COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

ol. 7, No. 10 APRIL, 1936 25c a copy

Station No. 3 of Rochester Gas & Electric Corporation showing 1935 Superimposed high-pressure extension

Superimposed High-Pressure Plant Extension of the Rochester Gas & Electric Corporation

Parallel Operation of Fans

FURNACE DESIGN

NUMBER TWO *of a series of advertisements in which subjects of current interest to utility engineers and consultants are briefly reviewed and present trends indicated. Subjects to be covered are listed below but deviations may be made either in sequence of list or titles.*

Superposition • Furnace Design

Heat Recovery • Heat Cycles

Boilers for High Pressures and Temperatures

Availability of Modern Boiler Units

DEVELOPMENTS of the past fifteen years in boilers, firing equipment and methods, and furnace construction have radically changed the problems of the furnace designer. The principal factors contributing to this change have been the water-cooled furnace and pulverized coal firing. Virtually all the advancement made is directly or indirectly traceable to these two factors.

Present-day practice favors furnace sizes large enough to permit of moderate combustion rates. This is true of furnaces for stoker as well as pulverized coal firing. The designer of modern stoker furnaces knows that half the heat in the fuel is liberated in the fuel bed and the remaining half in the combustion space. Accordingly, he provides liberal space above the stoker, at times approaching that of pulverized coal furnaces.

While it is possible to operate modern stokers at very high combustion rates for short periods, good practice with traveling grate stokers is a normal range of 30 to 45 lb per sq ft of grate surface, with peaks up to 60 lb, and with multiple retort stokers 30 to 50 lb, with peaks up to 65 lb. Heat liberation rates from the combustion of gases range from about 15,000 to 30,000 Btu per cu ft of furnace volume.

Some years ago there were predictions that in water-cooled furnaces fired by pulverized coal there would be virtually no limits to permissible heat liberation rates. Such predictions have not been realized because of difficulties resulting from slagging of boiler tubes and superheater elements. Experience has taught that it is not a question of how much coal can be burned in a given combustion space but rather how much gas, containing particles of ash near the fusion temperature, can traverse the heating surfaces without slagging those surfaces and clogging the gas passages. Present good practice in heat liberation rates in water-cooled furnaces fired by pulverized coal is generally in the range of 20,000 to 30,000 Btu per cu ft at normal loads and, with fairly good coal, 30,000 to 40,000 Btu during peak periods.

During the early stages of water-cooled furnace development there was some apprehension that complete water-cooling of furnace surfaces would lower the furnace temperature excessively and hinder combustion. Such apprehension has proved groundless. There are now many completely water-cooled furnaces burning pulverized coal and other fuels in suspension without combustion difficulties. There are also many traveling grate stoker installations with bare water-cooled arch and wall surfaces which are operating very satisfactorily.

No gain in the rapidity of combustion is obtained by raising the temperature beyond the point required for ignition. Once the fuel is ignited the combustible and oxygen combine as fast as they are brought into contact. The rapidity of combustion depends entirely on the rate at which contact is made.

With fuel burned in suspension, low rates of combustion are entirely a matter of proper fuel and air supply. The fuel must be supplied in a steady stream with just sufficient primary air for ignition. The remainder of the air must be supplied in the right quantity to the ignited fuel and in such a manner that it will mix with the burning fuel with concentration of combustion in a small space around the burner. A match can be burned in the largest completely water-cooled furnace without effect from the water-cooled surfaces because combustion is concentrated in a small space. Whenever it is necessary to operate a furnace at a very low average rate of heat liberation, it can best be accomplished by installing a small burner and supplying the burner with a constant flow of fuel.

All water-cooled furnaces are designed for natural circulation and are connected to the boiler proper by downcomers and risers. The trend is to locate the downcomers and risers within the boiler setting to obviate the necessity of covering them and to improve the external appearance of the unit.

When burning coals with low fusion point ash, water-cooled furnaces of the so-called slagging type have an advantage over the dry bottom type of furnace with respect to facility of ash removal. However, this type of furnace is at a disadvantage when it must be operated for extended periods at low ratings, as the ash during such periods will not be in the fluid state necessary for its removal. Also the difficulties which result from slagging of boiler and superheater surfaces with such coals still remain and become greater as the temperature of the superheated steam is increased. If it is necessary to burn coals with such low ash fusion temperature, provision must be made for frequent removal of the slag from the surfaces. With coals of moderately high ash fusion temperature, the so-called dry bottom furnace has certain advantages. The ash can be removed at regular intervals and there is no limitation to operation at low ratings.

The most successful method of firing pulverized coal is that which results in the most intensive mixing within the furnace proper. With intensive mixing, the combustion process is completed in a minimum of time and space and the combustion space is utilized with maximum effectiveness. Of the various methods of firing thus far developed, the tangential or corner method provides the most intensive mixing.

COMBUSTION ENGINEERING COMPANY, INC.

200 MADISON AVENUE • NEW YORK

COMBUSTION

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VOLUME SEVEN NUMBER TEN

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CCA

Troublesome Boiler Deposits—Their Formation and Logical Prevention

Practically every boiler water contains sulphates, silicates, carbonates, chlorides, calcium, magnesium and sodium, all present in very low concentrations.

In the generation of steam, and especially within the evaporating areas, these solutions when untreated finally reach concentrations wherein the least soluble of the constituents combine to produce the hard, adherent formations which are recognized as true boiler scale deposits.

Of the many materials which boiler waters carry, calcium is the principal offender in this connection, in that it causes such formations as calcium sulphate and calcium silicate. Under the same untreated conditions, magnesium also combines with silica in the formation of some form of magnesium silicate, which is equally as troublesome a factor as calcium silicate.

When a water is conditioned chemically for preventing these adherent formations, calcium is precipitated and may again become troublesome in locations within the boiler where the products of the treatment are permitted to settle together in dense formations, and especially where silica in appreciable quantities is either combined with calcium in these precipitates or is contained in the boiler concentrates in a soluble form as the hardening agent. In either event, silica is the trouble-producer here because of its properties in taking up water of hydration or crystallization.

These same boiler effects can be duplicated in a practical way:

First—Through evaporation by concentrating composite solutions of similar salts in an open receptacle to near dryness, and,

Second—Through the addition of water to either Plaster of Paris or Portland Cement, in both of which water of hydration or crystallization converts a dry pliable mass into a solid body with a high penetration resistance.

While the true calcium sulphate and calcium silicate scales form principally in the steam-generating areas, the hardened chemical precipitates are to be found in any section of a boiler, but principally in parts where the water circulation is more or less sluggish and opportunity for the accumulation of sludges in mass formations is permitted.

The per cent of silica contained in either the sludge deposits or boiler concentrates is, also, the one influence governing the hardness of such deposits.

In any event, **the summary of the several causes for hard depositions within boilers is confined to the evaporation of calcium compounds to the solid phase and to the cementing influences of water of hydration or crystallization in which the presence of silica plays a prominent role.**

As dissolved calcium is the predominant cause for the evaporated scale products the most logical procedure in preventing this is to keep this constituent out of solution in the boiler concentrates to the possible maximum extent through chemical precipitations. The more complete this is, the greater are the assurances against depositions of calcium sulphate and calcium silicate over the steam-producing areas within a boiler. The common commercial chemicals that are most effective in this connection are the soda-phosphates. Next to this is soda ash or carbonate of soda.

While this holds true in the treatment of the boiler concentrates for preventing hard scale depositions over the evaporating surfaces, **neither soda ash nor phosphates or any combination of these in any concentrations are effective in preventing the objectionable formations caused through hardening of chemical precipitates.** The only boiler conditioning materials which are proving a success today in destroying this influence are the **COLLOIDS** in combination with chemicals. **When properly selected to function under the range of boiler concentrates to which they are to apply,** they invariably **prove themselves masters in preventing these hard sludge accumulations.**

A chemical, therefore, that effects the greatest possible removal of calcium from solution in the boiler concentrates and simultaneously prevents the hardening of sludges is the best type of treatment to employ.

PHOSCALOID is such a conditioning agent, because—This is a complex organic compound of PO_4 containing 45% P_2O_5 and **colloids of the most effective type.**

It is also very flexible in its conditioning of boiler waters, forming mono, di- and trisodium phosphate in any required combinations when mixed with caustic soda, applying equally effective for internal or direct treatments or as a supplemental treatment in the operation of lime-soda or zeolite softeners.

It, also, keeps the sludge products of the chemical treatments in that liquid state by which they are very largely removed under operating conditions through the blow-off.

Best of all, PHOSCALOID reduces the PO_4 requirements 25 to 45% when compared to the use of straight commercial soda phosphates.

While PHOSCALOID has primarily been developed for the treatment of water in which silica is the troublesome factor, it will also successfully condition any sulphate waters against scale depositions and/or nasty sludge conditions. While this is the case, PHOSCALOID, like any other phosphate treatment, is four to five times as expensive as soda ash which can be made equally effective when combined with the right colloid in this treatment of sulphate waters. This single use of colloids has special value in the conditioning of boiler feedwaters through lime-soda softeners, where their requirements are the least and substitution for phosphates can effect a real reduction in treating costs. To meet this substitution successfully, **RICECALOID** has been developed.

RICECALOID'S success in this special work has been demonstrated under severe operating conditions by the fact that it—

Eliminates sludge as a problem in boiler operations through the use of this product in the amount of 2% of the weight of the sludge-producing solids that are delivered to a boiler.

It is, also, outstanding in its value because—

It contains 100% available colloids;

It is applicable to the widest range of boiler water alkalinities, and,

It materially reduces the chemical requirements in treating without detracting from the final results.

Neither PHOSCALOID nor RICECALOID have been developed as panaceas in the conditioning of boiler feedwaters but are intended only as supplemental treatments for use with commercial chemicals in bringing about better all-around results at lower costs.

Cyrus Wm. Rice, *President*

P.S. RICECALOID is sold in packages as small as 25 pounds. PHOSCALOID comes in 325- and 650-pound barrels. Both are the result of better than 20 years intensive water treating experience.

CYRUS Wm. RICE & CO., INC.

HIGHLAND BUILDING—PITTSBURGH, PA.

PLANT EXTENSION of the & Electric Corporation

A description of the first superimposed unit in Station No. 3, consisting of a 250,000 lb per hr bent-tube, pulverized-coal-fired boiler supplying steam at 650 lb, 750 F to a 6000-kw non-condensing turbine-generator which exhausts to the existing low-pressure turbines. Construction on a duplicate of this high-pressure unit will be started shortly.

By IRVIN G. McCHESNEY,
Test Engineer
Rochester Gas & Electric Corporation

RAPID increase of electric load in the Rochester area forced the Rochester Gas & Electric Corporation last year to consider an immediate extension of its steam generating capacity. In consequence, a program of modernization and expansion was mapped out for Station No. 3. This is a 200-lb station built some years ago containing ten 600-hp and twelve 875-hp boilers serving one 15,000-kw, one 12,500-kw and three 10,000-kw turbines having 11,000-volt, 60-cycle turbine-generators. All the turbines are equipped with jet condensers.

The proposed changes included two superimposed high-pressure boilers, each rated at 250,000 lb per hr capacity, supplying steam to two 6000-kw turbine-generators exhausting to the existing low-pressure turbines. These units were to be installed successively, followed later by replacement of the jet-condensing turbines with more efficient machines having surface condensers. This plan deferred excessive write-off of serviceable low-pressure turbine capacity and gave the immediate economies of high-pressure and high-temperature production.

The first superimposed plant addition has been in operation since January 2, 1936. This is designed to

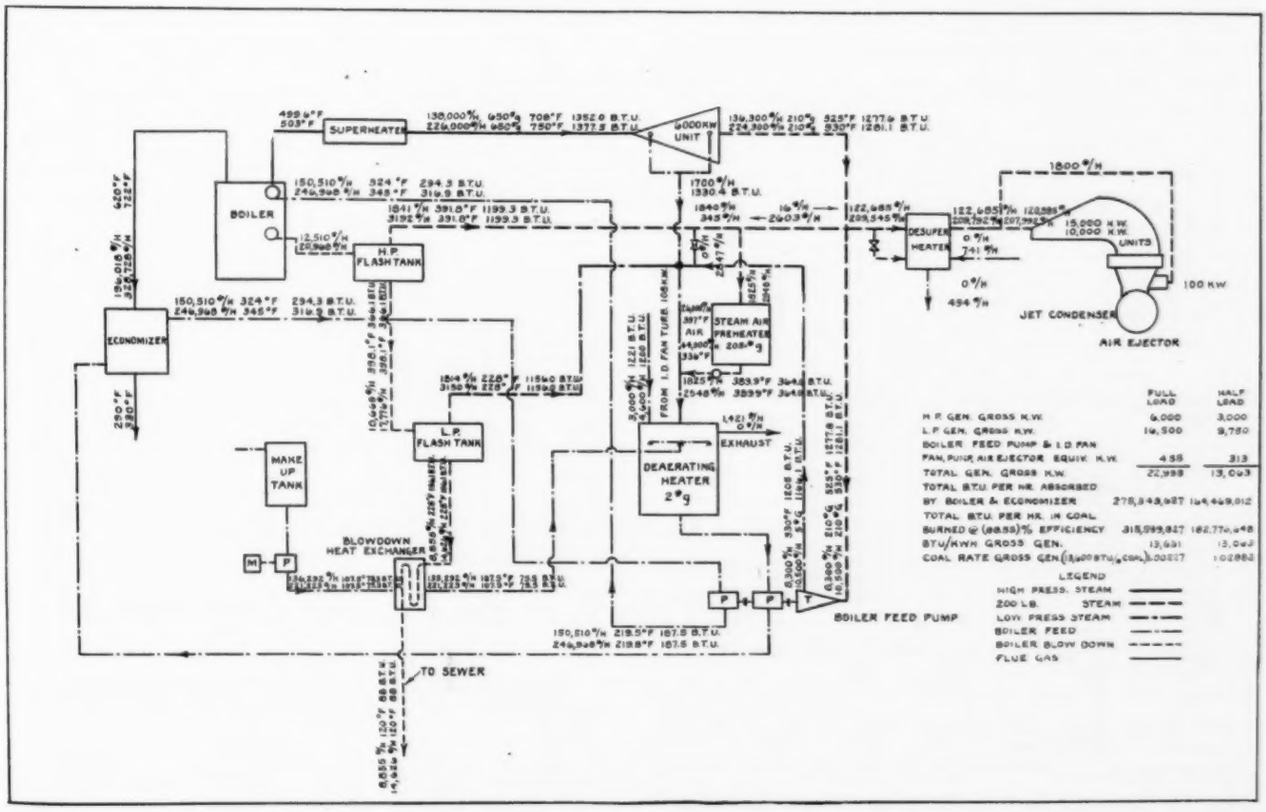


Fig. 2—Full and half load flow diagram of plant

operate at 650 lb per sq in. gage and 750 F steam temperature at the turbine throttle, the steam conditions in the old plant and the high pressure-turbine performance having determined the pressure and temperature of the steam in the high-pressure extension.

The E. M. Gilbert Engineering Corporation was retained as the consultant on the design of the plant.

One of the outstanding features of the design is the requirement of approximately 90 per cent make-up feedwater, due to commercial steam sales without condensate return and to the low-pressure turbines being served by jet condensers. This consideration led to a large water-treating installation. S. T. Powell, acting as chemical consultant, has given invaluable aid in solving this unique problem of boiler feedwater treatment.

The low-pressure turbines are not bled for feed heating. The decision to eliminate bleeding was partly to simplify plant design, and also because the exhaust heat from the 15,000-kw low-pressure turbine is recovered intermittently during periods of pumping raw river water to storage in the water-treating plant. During pumping periods the water-steam ratio of the jet condenser is reduced and approximately the entire discharge of the condenser is recovered at an average temperature of from 100 to 110 F, depending upon the season and the heating requirements. Furthermore, feedwater heating is accomplished by exhausting plant auxiliaries and a small amount of 210-lb bled steam into a deaerating heater. The feed is then passed through an economizer having a surface equivalent to 90 per cent of the boiler and water-wall heating surfaces. Water is fed to the boiler at 345 F. Steam-air heating is employed for drying coal.

Detail of Plant Cycle

The diagram, Fig. 2, defines the flow of water and steam in the plant at full load and at half load. The net heat rate at full load, based on the guaranteed characteristics of the plant, is 14,500 Btu per kwhr which, with the coal being used, corresponds to 1.07 lb per kwhr.

Steam leaving the boiler drum at 685 lb per sq in. gage passes through the superheater and reaches the turbine throttle at 650-lb gage and 750 F. The turbine exhausts through a desuperheater into a 210-lb main of the old plant at 530 F. Four degrees desuperheating are required at full load and twenty-six degrees at half load. It is assumed in the flow diagram that all desuperheated steam entering the 210-lb main is used for low-pressure generation.

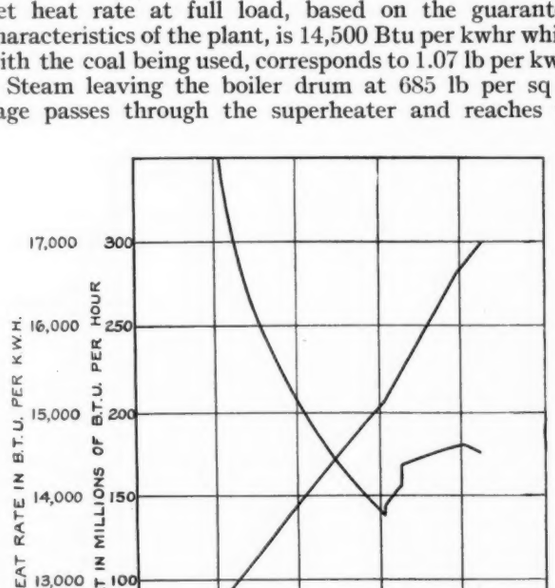


Fig. 3—Total Btu consumption and Btu rate characteristics of plant, based on all high-pressure turbine exhaust to low-pressure turbines

TABLE I

FULL AND HALF-LOAD PERFORMANCE CHARACTERISTICS OF THE PLANT—GROSS GENERATION

	Full Load	Half Load
High-pressure gross generation, kw	6,000	3,000
Low-pressure gross generation, kw	16,500	9,750
Equivalent kw allowance for auxiliaries	455	313
Total gross generation	22,955	13,063
Total Btu per hr absorbed by boiler and economizer	275,343,627	164,469,012
Total Btu per hr in coal burned	313,599,827	182,776,648
Btu per kwhr gross generation	13,631	13,063
Coal rate on gross generation at 13,600 Btu per lb coal	1.002	1.029

In operation, blowdown from the boiler is approximately 10 per cent of the steam generation. This blowdown is flashed at 210 lb per sq in. gage and again at 5 lb and is finally passed through a heat exchanger, giving up its heat to the makeup feedwater. Blowdown is discharged at a final temperature of 120 F.

Because of rapid concentration of solids in the desuperheater water the blowdown from the desuperheater is relatively large. This is taken directly to the blowdown heat exchanger.

Table I gives the full-load and the half-load performance of the plant.

Heat Input and Rate Curves

The plant heat consumption and rate curves given in Fig. 3 illustrate the variation of heat input to total net kilowatt output and are based on the use of all steam for electric generation. These curves indicate a heat rate from 14,000 to 14,600 Btu per kwhr with load varying from half to full load, or less than 1.1 lb of coal per kilowatt-hour with coal of 13,600 Btu per lb as received.

In addition to electric generation the plant supplies industrial and process steam. In severe weather the send-out steam load peaks are from 200,000 to 230,000 lb per hr and drop to about 50,000 lb per hr in the summer. Send-out steam at present is all throttled from the 210-lb steam main. The exhaust steam from the high-pressure turbine is used for both electric generation and steam send-out.

Boiler and Furnace

A CE four-drum bent-tube boiler having 250,000 lb per hr maximum capacity was selected. As will be seen by reference to Fig. 5 there is a fifth, or dry, drum 48 in. diameter and 23 ft 7 in. long mounted above the other drums and containing a steam washer. All the drums are fusion welded and were inspected by X-ray. Table II gives the distribution of heating surfaces and

TABLE II

DISTRIBUTION OF HEATING SURFACES OF THE STEAM-GENERATING UNIT

Boiler	15,300 sq ft
Water walls	3,990 sq ft
Superheater	4,032 sq ft
Economizer	20,808 sq ft
Furnace volume	13,720 cu ft

TABLE III

PERFORMANCE CHARACTERISTICS OF THE STEAM-GENERATING UNIT-FURNACE, BOILER, SUPERHEATER AND ECONOMIZER

Evaporation Lb Steam per Hr	Draft Loss of Unit, In.	Gas Temperature, deg F Boiler Outlet	Gas Temperature, deg F Economizer Outlet	Efficiency, Per cent Boiler	Efficiency, Per cent Unit
117,500	1.30	584	270	81.2	89.4
235,000	4.75	720	330	77.1	87.6
250,000	5.40	740	335	76.7	87.3

Table III the performance specifications of the steam-generating unit.

Steam load on the plant varies with the amount of power generated by hydroelectric stations on the company's system, with purchased power and with steam send-out. Because of these load variations and the availability of suitable coals having high ash-fusion temperatures a dry-bottom furnace design was selected. Most of the present available coals are from the Allegheny County, thick Freeport seam. A large double water screen protects the ashpit and a Hydrojet installation is employed for ash removal.

The entire rear wall and lower half of the side walls are of fin-tube construction and the upper side walls of the furnace are of DeWolf arch construction, sealed with 1 in. of Stic-tite on the outside. The furnace sides of the upper walls are not protected by water tubes. Circulating tubes serving the fin-tube side walls pass up through the supporting steel of the upper side wall construction and the steelwork supporting the walls of the upper half of the furnace is air ventilated. The fin-tube walls are backed with 2 in. of Moldit. All the furnace walls and the roof of the furnace are insulated with 3 in. of rockwool and sealed with 12-gage steel casing. The side and rear walls of the boiler are also sealed with 12-gage steel casing.

The front wall is of 18-in. solid brick construction up to the top of the burners and 9-in. DeWolf arch brick construction to the junction of the furnace roof which is of $2^1/_2$-in. first quality firebrick covered with a protecting layer of 3 in. of rockwool and a 12-gage steel casing. The front wall is protected on the furnace side by bare tubes on 12-in. centers.

Superheater and Economizer

The superheater is of the Elesco type having 4032 sq ft of surface and consists of twenty-four two-loop semi-radiant elements and fifty-three four-loop convection elements $1^3/_4$-in. outside diameter.

A large economizer was necessary to heat the feedwater from 220 to 345 deg. This is of extended-surface Foster Wheeler counter-flow design having 20,808 sq ft of surface and approximately 78 per cent of the heat entering the economizer is absorbed by the feedwater.

Coal Preparation and Firing Equipment

Coal is trucked from a railway siding, crushed in a Hammermill crusher to $1^1/_4$-in. slack and elevated to a 500-ton overhead bunker. It is then fed through two 18-in. Link-Belt duplex bunker gates to Jeffrey vibrating type feeders, the latter supplying two No. 4 Foster Wheeler Tricone ball mills. These mills are driven by 150-hp, 870-rpm line-starting motors connected by snub couplings to the reduction gear-mill drive. The present run of coal is from 0.60 to 0.65 grindability by the Hardgrove scale and the mill is expected to grind to a fineness in excess of 70 per cent through a 200-mesh screen. Each mill has a capacity of 15,200 lb of coal per hour. The mill air is heated to approximately 130 F, measured in the mill discharge, steam-heated primary air being drawn through the mill by an exhauster fan

TABLE IV

EXPECTED HIGH-PRESSURE TURBINE PERFORMANCE

Kw Load	Steam Flow, Lb per Hr	Water Rate, Lb	Exhaust Temp., deg F
1,575	93,615	59.40	580
3,090	136,530	44.20	550
4,645	181,213	39.10	535
6,150	230,280	37.50	530

Conditions are given for 650 lb per sq in. gage and 750 F at the throttle to 210 lb sq in. gage back pressure. Gland steam requirements are 1700 lb per hr.

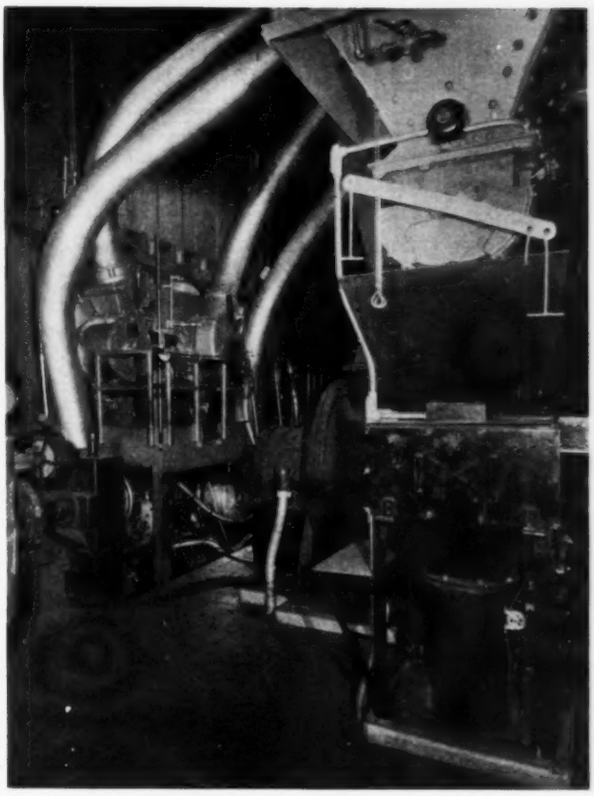


Fig. 4—Feeders, exhauster fans and burners

of the paddle-wheel type. The fan construction is of cast-iron and protected by replaceable steel liners.

The amount of coal in the mill is maintained approximately constant by automatic feeder regulation, which is actuated by two tubes measuring the draft in the mill. As the lower tube becomes submerged a differential pressure develops between the upper and the lower tube, cutting off coal feed. When the coal level falls to expose the lower tube the difference in draft between the two tubes becomes zero and the feeders start feeding coal.

The amount of coal fed to the furnace depends upon the amount of air flow through the mill. This air flow is regulated at the exhauster inlet where air is bled in from the room. The exhauster operates at approximately constant air discharge regardless of the boiler load and protects the firing system from flare-backs. With light load a large portion of primary air enters from the room at the exhauster inlet, and only a small portion is taken through the mill. At full load the larger portion of air is drawn through the mill. Secondary air is served to either mill by a Clarage, double-inlet, double-width fan. Air flow is controlled by Vortex inlet vanes and furnace pressure controls the amount of secondary air.

The coal is fed to the furnace through four CE Type R forced-draft burners, there being two burners per mill. The coal is carried up from each exhauster to an overhead splitter and down to the burners. Primary air and coal enter at the center of the burners and secondary air through an outer concentric ring.

A Clarage induced-draft fan is located in the upper floor of the building between the Cottrell precipitator and the stack. At full load on the plant the fan handles 103,500 cfm of gases at 335 F against 4.25 in. of water. This fan is driven by a 200-hp turbine with full load speed of 3645 rpm through a herringbone reduction gear driving the fan at 685 rpm. The turbine steam conditions are 210 lb per sq in. gage and 525 F.

The arrangement of firing equipment is shown in

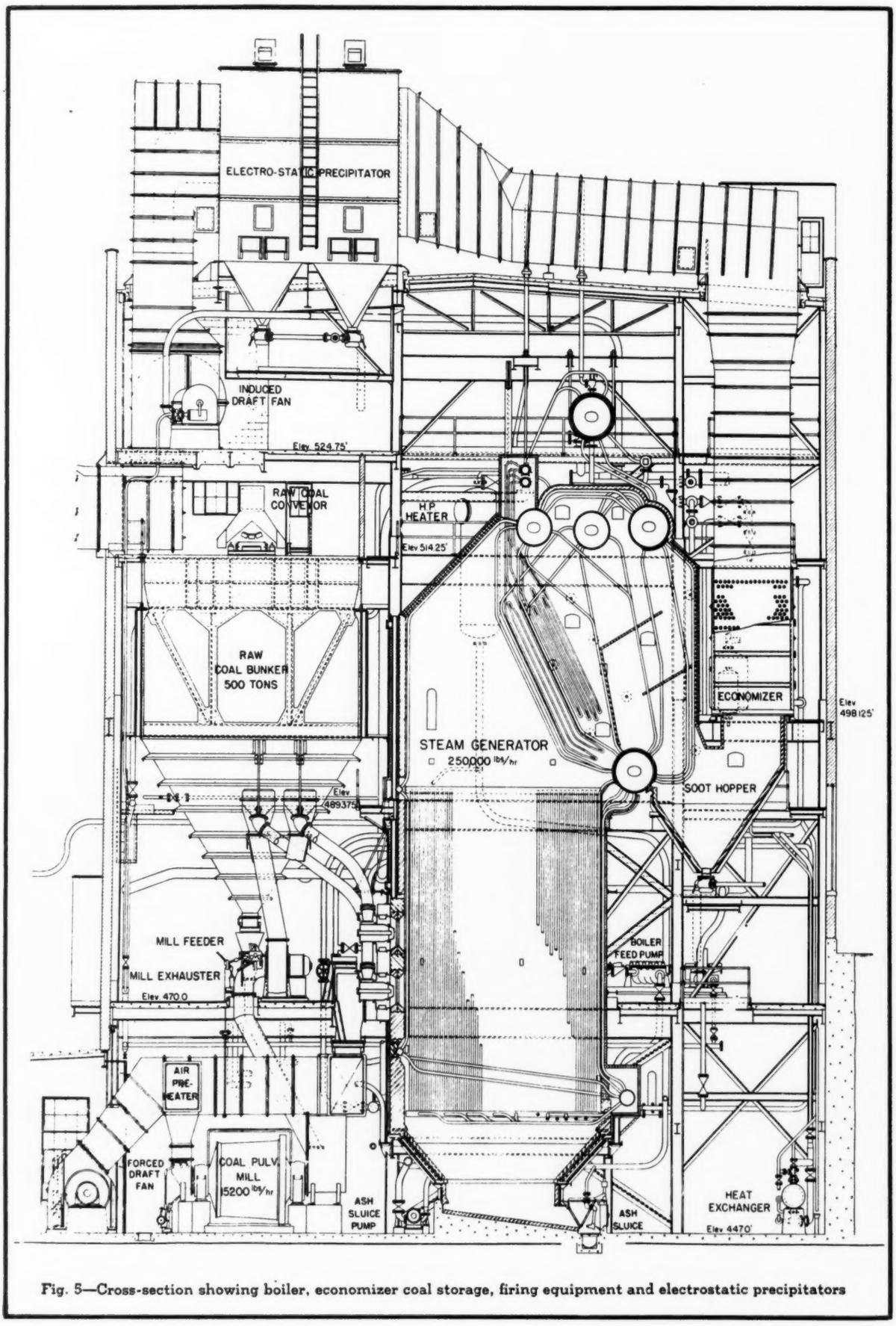


Fig. 5—Cross-section showing boiler, economizer coal storage, firing equipment and electrostatic precipitators

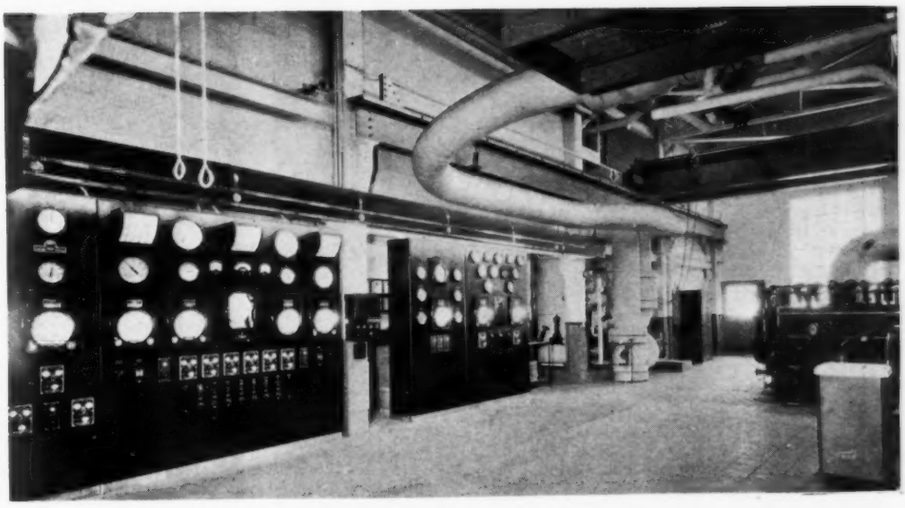


Fig. 6—Instrument and control panels, desuperheating equipment and turbine

Fig. 5; the mills and reduction gear drive in Fig 8; and the feeders, exhausters and burners in Fig. 4.

Chemical Treatment and Flow of Feedwater

The Genesee River is the source of raw water for the plant. Analysis of this river water varies with the ratio of ground water to surface water, dilution from the Barge Canal and industrial waste contamination from its tributaries. The present flow has a relatively high percentage of surface run-off water and the hardness varies from 70 to 300 ppm with an average condition of approximately 170 ppm.

Water pumped from No. 7 turbine at 100 F is treated with lime, soda and ferrous sulphate in the Scaife intermittent treating plant that serves the old boiler house. After leaving the treating plant and after sedimentation, the water, without being filtered, is pumped continuously as required through the blowdown heat exchanger and into the Cochrane hot-process deaerating softener where all the oxygen is removed and the hardness is reduced to zero. The initial treatment reduces the hardness to 17 ppm or less. Chemical proportioners feed sodium sulphate to the suction of boiler feed pumps for the adjustment of the sulphate-carbonate ratio. Disodium phosphate is added to the softener to reduce the residual hardness to zero. An excess of 5 parts per million or less of free soluble phosphate (PO_4) is maintained in the feedwater.

Water leaving the deaerator is filtered through closed filter beds of graded magnetite and passed to the feedwater pumps. The two feed pumps are of tandem design, the first a 3-stage pump feeding water at 275 lb per sq in.

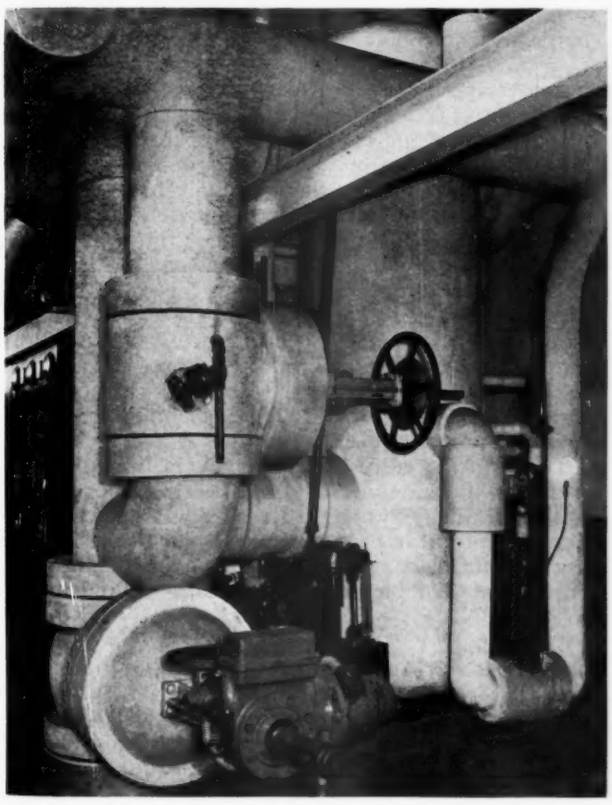


Fig. 7—Desuperheating Equipment

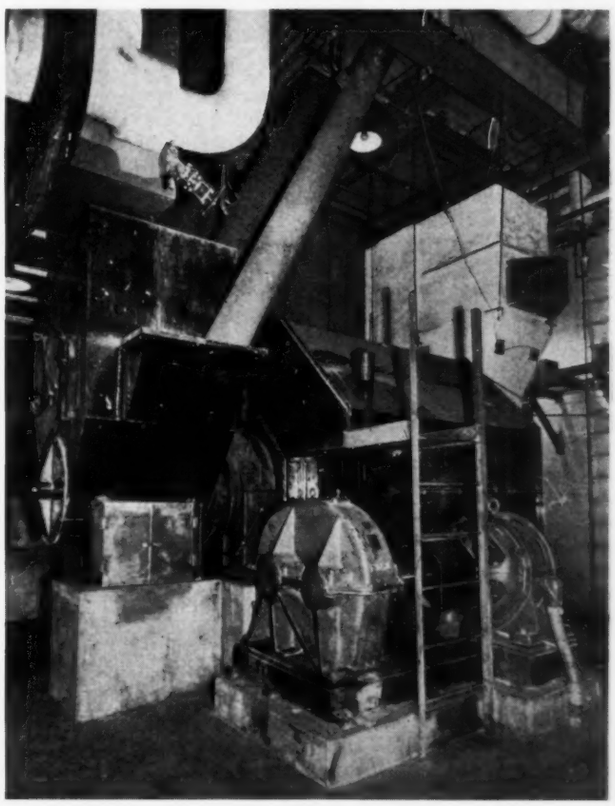


Fig. 8—Mill showing classifier and drive

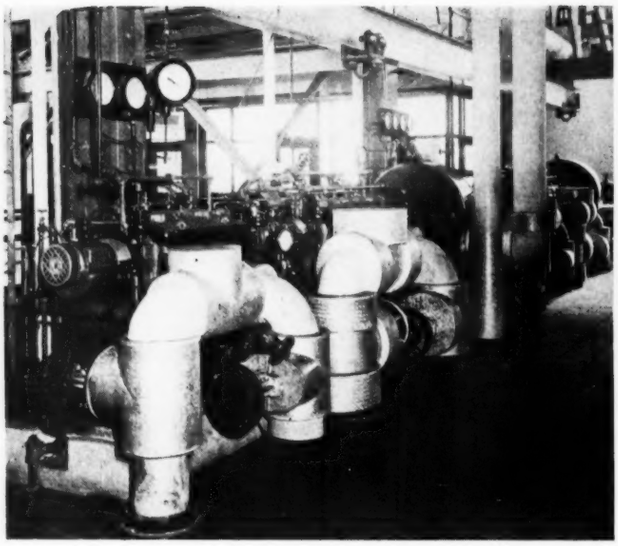


Fig. 9—Turbine-driven tandem feed pumps

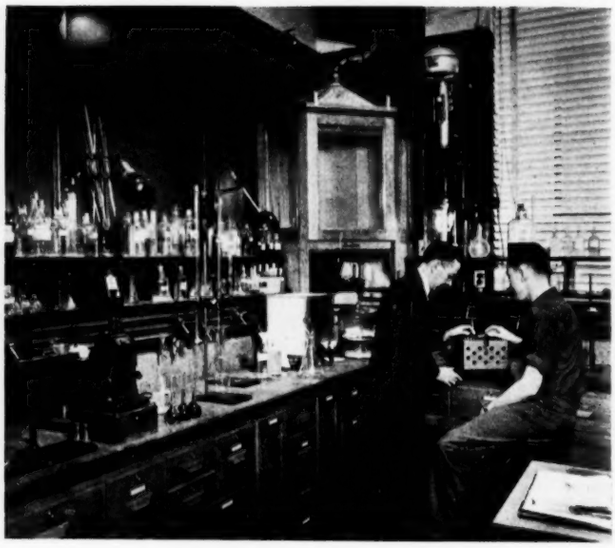


Fig. 10—Chemical laboratory

to the economizer, and the second, 5-stage portion of the pump, raising the pressure to 780 lb for boiler feed. The water goes from the high-pressure pump to a steam washer. Here the incoming water washes the saturated steam passing from the rear upper drum through the steam washer to the saturated header of the superheater.

Boiler water concentrations are controlled by continuous blowdown to 3000 ppm or less total solids at the present time. The blowdown is regulated by a forged-steel needle valve allowing accurate adjustment of flow.

The plant is equipped with a chemical laboratory (see Fig. 10) to facilitate chemical control of water conditions, sampling lines being provided to draw water and steam from various points in the system for analysis.

Turbine-Generator

The turbine-generator is a G-E 6000-kw 80 per cent power factor, 3-phase, 60-cycle, 3600-rpm, 7-stage machine operating at 11,500 volts and having a direct-connected exciter. The ventilating air is water cooled and recirculated. Oil to the bearings and governor is water cooled and provision is made to centrifuge it when required. Steam is supplied at 650 lb and 750 F and discharges to the desuperheater at 210-lb gage and 530 F at full load. Variation of turbine performance with load is shown in Table IV. The turbine has six governor valves which in normal operation will carry a load of 6000 kw, and a seventh overload valve is installed to carry loads up to 7000 kw.

Particular attention was given in the design to relieving possible temperature stresses due to piping. The inlet piping, seen in Fig. 1, is made up of creased bends. The exhaust line seen below the turbine is rigidly fastened to the turbine and to the desuperheater. The off-take from the desuperheater is a long vertical run and the exhaust piping stresses are relieved by allowing the desuperheater to slide on its supports. A by-pass is installed to throttle high-pressure steam to the desuperheater.

Desuperheater

Steam to the low-pressure steam mains should not be over 530 F. To insure this the desuperheater is designed to care for variations of turbine discharge temperature and to desuperheat throttled high-pressure steam. A Blaw-Knox desuperheater, Fig.7, 36-in. diameter and 13 ft high was selected. The main volume of steam passes straight through the top of the desuperheater, a butterfly valve being installed in the inlet top connection. Pressure drop due to the partial closure of this butterfly valve causes steam to enter through a by-pass at the bottom of the desuperheater, which steam is completely saturated and passes upward to mix with the superheated steam in the top. Baffles are arranged to prevent excessive moisture in the saturated steam from carrying up into the mixture. The temperature of the desuperheated steam controls the butterfly valve position automatically and water level in the lower portion of the desuperheater is regulated by a Bailey type thermal-hydraulic single-element regulator.

Automatic Control

Bailey control is used throughout the plant, automatically controlling the fuel and air, feedwater flow, flow through the reducing valve and the desuperheated steam temperature. Provision is made also for remote hand control of all equipment from the panel board, or manual control for each piece of apparatus. The combustion control not only maintains desired steam pressure, but also regulates the air supply to assure correct combustion conditions at approximately 20 per cent excess air. Readjustment is obtained through the use of a boiler meter which records air flow and steam flow.

Feedwater supply to the boiler is controlled through a 6-in. air-operated V-ported control valve, actuated from steam flow, water flow and drum level. This feedwater control is commonly known as the three-element type. In addition, the speed of the feed pumps is controlled through an air-operated valve to maintain proper differential pressure between feedwater and boiler drum.

The reducing valve by-passing steam from the 650-lb to the 210-lb main is also controlled with a V-ported valve.

Interlocking relays are so arranged as to trip the boiler plant equipment in proper sequence, due to the failure of any piece of plant equipment, and an annunciator panel will indicate trouble on essential plant equipment.

Auxiliary Power Supply

The 440-volt auxiliary power supply is taken from two 1500-kva transformers, one taking power from the 1450-volt and the other from the 11,000-volt bus. Switching equipment is operated by electrical contactors grouped under air breakers. The electric auxiliary equipment is further protected by a system of interlocks that insure operating equipment in proper sequence.

Principal Equipment in Rochester Gas & Electric Corporation Extension

Boiler and Furnace

One *Combustion Engineering Company*, 4-drum, bent-tube boiler, fired with pulverized coal through front wall by 4 burners. Heating surfaces: Boiler 15,300 sq ft, water walls 3990 sq ft, superheater 4450 sq ft, economizer 20,808 sq ft; Furnace volume 13,720 sq ft. Boiler-tube arrangement, 36 sections of 20 each, tubes 3 1/4 in. O.D. Drums fusion welded, 42 in. and 48 in. diam, 1 19/32 to 3 1/8 in. shell thickness. Dry drum 48 in. above boiler and connected to the rear drum by thirty-four 3 1/2-in. tubes. Furnace walls: Bare tubes, plain and fin type, backed by refractory, insulation and steel casing. Operating conditions: Maximum continuous output 250,000 lb per hr, 660-lb pressure, 750 F total steam temperature; feedwater entering at 345 F.

Firing Equipment

Two *Foster Wheeler* Tricone ball mills, 15,200 lb per hr each, driven by 150-hp *Westinghouse* motor through a *Bethlehem* snub coupling; one exhauster fan. Feeders are *Jeffrey* vibrating type. Mill exhausters are paddle-wheel type, having a cast-steel spider with mild steel blades, mounted on shaft of a 75-hp, 1200-rpm *Westinghouse* motor.

FORCED-DRAFT FAN, furnishing primary air to mills and secondary air to burners is a *Clarage* double-inlet type having adjustable Vortex control and direct-connected to a 75-hp, 860 rpm, squirrel-cage motor through a flexible Fast coupling. Maximum capacity 69,000 cfm.

STEAM-AIR HEATER. Six Aerofin heater units (*American Blower Corp.*) containing 1921 sq ft. Calculated performance, with mill pulverizing 15,200 lb per hr, is 30,000 lb air per hr at 80 F entering air, 347 F leaving air. Condensate, 2390 lb per hr.

BURNERS. Four *Combustion Engineering* Type R burners arranged 2 high and 2 wide, requiring 4 in. static pressure of primary air at burner inlet when supplied with 7600 lb of coal per hour, and 3800 cfm of air from mill.

Superheater

Supplied by *The Superheater Company;* 4450 sq ft heating surface made up of 35 two-loop, semi-radiant elements and 53 four-loop convection elements. A 2 1/2-in. *Consolidated* safety valve set at 745 lb is provided.

Economizer

Foster Wheeler counter-flow type, 20,808 sq ft, 24 rows high, 17 wide, 2 in. tubes with cast-iron gills. *Diamond* soot blowers, 4 horizontal rows, 16 elements.

Ash-Handling Equipment

Allen-Sherman-Hoff Co. Hydrojet ash system for furnace bottom, Hydrovac fly-ash system for economizer and electrical precipitator. Ash sluiced through a concrete trench having nickel cast-iron liners.

Soot Precipitator

Cottrell precipitator. Two units of 11 ducts, collecting electrodes of the rod type with a solenoid-operated rapping mechanism, installed ahead of induced-draft fan.

Induced-Draft Fan

Clarage Fan Co., double-width, double-inlet, bottom discharge, taking gases from precipitator and discharging to existing stack. Fan driven by 200-hp *Allis-Chalmers* turbine through single reduction gear. Turbine operates at 210 lb, 525 F and exhausts at 5-lb gage to deaerating heater; regulation by *Bailey* combustion control.

Boiler Feed Pumps

Two *Allis-Chalmers* pumps, each in two units consisting of a primary 3-stage and a secondary 5-stage pump on a common base with turbine. Capacity, primary pump 618 gpm, secondary pump 730 gpm; total dynamic head of secondary 1485 ft. Primary pump takes feedwater from deaerating heater at 212 to 220 F and pumps through economizer to secondary pump which receives water at about 345 F and discharges to boiler. Pumps driven by one *Allis-Chalmers* and one *Moore* non-condensing turbine. Regulation by *Bailey* regulating valves in steam supply lines.

Water Purification Equipment

Cochrane 32,000-gph deaerating-type, hot-process water softener consisting of sedimentation tank with feeding equipment for chemicals, phosphate and sodium sulphate, filters and water wash pumps, with auxiliary equipment.

Desuperheater

Blaw Knox design 36 in. diam. by 13 ft high. Steam to present low-pressure turbine reduced to 525 F whether from high-pressure turbine exhaust or by-pass from boiler. Feedwater and blowdown regulated by *Bailey* thermo-hydraulic generators.

Continuous Blowoff Equipment

Supplied by *Cochrane Corp.* and consisting of one 2-in. forged-steel needle control valve, one high-pressure flash tank built for 250 lb, one low-pressure flash tank for 50 lb and one 625 sq ft 4-pass U-tube heat exchanger built for 50 lb. Capacity is sufficient for two boiler units.

Coal Handling

Robins Conveying Belt Co. capacity 125 tons per hr, consisting of apron feeder, Hammermill crusher, belt and bucket elevator, belt conveyor and tripper, with electrical interlocking equipment. Coal is delivered to steel plate, hopper-bottomed bins, Gunite lined.

Boiler and Furnace Setting

Combustion Engineering Company, sub-contractor, *Wm. Summerhays Sons Corp.*, Rochester.

FRONT WALL, 18-in. firebrick to top of burners; above this *DeWolf* 9-in. refractory with 1-in. Stic-tite (*Refractory and Engineering Corp.*) on back. Entire wall insulated with 3-in. rockwool blanket and steel casing.

SIDE WALLS, *DeWolf* type refractory 9 in. and 7 1/2 in. thick insulated with rockwool and steel casing.

REAR WALL, above soot hopper to upper rear drum 2-in. firebrick tile with 3-in. rockwool and steel casing.

BOILER AND FURNACE ROOF, carried on circulating tubes, consists of 2 layers of 2 1/2-in. firebrick insulated with rockwool and steel casing.

SIDE WATER WALL backed by 2 1/2-in. shaped firebrick to fit behind fin tubes with 1-in. Stic-tite, air space, 3-in. rockwool and steel casing.

REAR WATER WALL backed by 2 1/2 in. of Moldit behind fin tubes held in place by steel plate resting against the downtake tubes, 3-in. rockwool and steel casing.

Harbison-Walker refractories used.

Boiler Accessories

WATER COLUMNS AND WATER LEVEL INDICATORS. *Diamond Power Specialty Corp.* Two water columns for 752-lb drum pressure; one water-level indicator connected to one of the water columns; one 21 1/2-in. vision length flat-glass water gage with illuminator; and one 21 1/2-in. vision length color water gage with reflector and floor mirror.

BLOWDOWN. Three *Cochrane* forged-steel blowoff valves for 900 lb and one 2-in. 1500-lb *Edward* forged-steel needle valve.

SAFETY VALVES. Three *Consolidated Ashcroft Hancock* valves for 900-lb pressure, set at 750-lb, 755-lb and 760-lb gage, respectively.

SOOT BLOWERS. *Diamond* automatic valve-in-head, sixteen 1 1/2-in. units in boiler and sixteen 2-in. units for economizer.

Ducts and Breechings. *Connery & Co.*

Elevator. *Graves Elevator Co.*, Rochester, combination freight and passenger.

Structures. *A. W. Hopeman & Sons Co.*, General Contractor. Structural steel by *Genesee Bridge Co.*

RIVER WATER STRAINER. One 1050-gpm strainer for generator air cooler, transformers and house-service water.

TEMPERATURE RECORDING INSTRUMENTS AND GAGES. *Taylor Instrument Co.*

Piping and Valves

All piping fabrication and erection by *W. K. Mitchell & Co., Inc.*

HIGH-PRESSURE STEAM. Seamless steel pipe A.S.T.M. Specification A-106–34T. Schedule 80. Gaskets, steel ring, dead soft 1/32 in. thick. *Lunkenheimer* valves, *Edward* non-return valve. Serrated faces on valves and flanges where used, all other joints welded.

HIGH PRESSURE EXHAUST. Seamless steel pipe, A.S.T.M. Spec. A-106–34T. Schedule 20. Gaskets, *Klingerite* 1/16 in. thick, valves, *Reading-Pratt & Cady Co.*

BOILER FEED DISCHARGE. Pipe and gaskets same specification as high pressure steam, *Lunkenheimer* valves.

Control Equipment

Bailey control system, entirely automatic (supplemented by hand). Primarily, the steam pressure, through a master pressure controller, determines the compressed air pressure regulating the fuel supply, and secondarily, the steam flow-air flow mechanism adjusts the compressed air pressure controlling the speed of the turbine-driven induced-draft fan for the coal given. The forced-draft fan is regulated by furnace pressure which is maintained constant

Main Turbine Generator

General Electric Co. 6000-kw, 80 per cent power factor, 3-phase, 60-cycle, 11,500-volt, 3600-rpm, impulse-type, non-condensing unit, with direct-connected exciter. Air for generator ventilation cooled by a 6-pass air cooler of 3350 sq ft surface, requiring 160 gpm cooling water at 80 F. Direct-coupled 40-kw exciter. Steam at throttle 650-lb gage, 750 F exhausting at full load at 210-lb gage, 530 F.

Valve Control. "Limitorque," *Philadelphia Gear Works.*

Station Power Transformers

1500 kva, 3-phase, 11,000/440 volts and 4150/440 volts, (inert gas) *Allis-Chalmers Mfg. Co.*

Station Lighting Transformers

25 kva single-phase, *General Electric Co.*

Emergency Lighting. D.C. from station battery.

House Switchboard

440-volt, a.c. open, latched-in contactors, grouped behind air circuit-breakers. *I.T.E. Co.*

GENERATOR OIL CIRCUIT-BREAKER. 600 amp, 15 kv *General Electric Co.*

GENERATOR AND TRANSFORMER CABLES. Paper and lead, 15 kv, *General Electric Co.* and *Safety Cable Co.*

STATION AUXILIARY AND LIGHTING CONDUCTORS.

2500-volt *Kerit Insulated Wire & Cable Co.* 600-volt, *Kerite Insulated Wire & Cable Co.* 600-volt *Rockbestos Products Corp.*

MOTOR-GENERATOR SET. 5-kw, 125-volt d.c. *Electric Products Co.*

Dr. Max Jakob, German engineer and scientist in steam table research, is on a lecture tour in this country where he will talk before several universities and local sections of the A.S.M.E.

Francis Hodgkinson, well known turbine designer, has recently retired from the Westinghouse Electric & Manufacturing Company.

H. K. Kugel, formerly in charge of the Smoke Inspection Department of Cleveland has been appointed Smoke Regulation Engineer for the District of Columbia.

J. D. Yoder, formerly vice president and general manager of the Cochrane Corporation has accepted a sales executive position with the Permutit Company of New York.

PARALLEL OPERATION OF FANS

By H. F. HAGEN, Dir. of Research
B. F. Sturtevant Company

In discussing the factors essential to successful parallel operation of fans the author employs graphical analyses based on system curves of constant resistance. The method of determining fan characteristics is reviewed and characteristics of different types of fans are touched upon; curves are included covering parallel operation of fans running at different speeds.

THE successful paralleling of two or more fans depends upon their characteristics and the resistance to air flow of the connected system of ducts, dampers, chambers, nozzles or other obstructions.

Fan characteristics are determined by test at constant speed. Readings are taken that give volume, pressure and horsepower over the complete range of fan output from blocked-tight pressure with zero volume to wide-open volume at zero pressure. A sufficient number, eight conventionally, of intermediate points are taken, giving the pressures the fan will produce at the various volumes and the power consumed. Restrictions to permit these different volume flows are sized to give substantially equal intervals, and curves drawn through the plotted test points then show every value of pressure and horsepower, with the corresponding volume, that can exist with that particular fan at the speed during the test. The plotting is most useful with volume as abscissae and pressures as ordinates for the pressure characteristic, and horsepower as ordinates for the horsepower characteristic. In mathematical terminology these characteristics are the loci of pressure-volume and horsepower-volume, and the fan performance under any conditions of duct resistance must lie on these curves.

An unavoidable complication arises at this point. True pressure is dependent upon potential energy and may be defined as "the potential energy per cubic foot of air." Conventionally, the term "Static Pressure" is used for this quantity. It is entirely valid to relate the closeness of the gaseous molecules to the position implication of the term potential. Air, however, has mass, and, in motion, kinetic energy. The amount of this energy per cubic foot is in dimensions of pressure and is the so-called "Velocity Pressure." The sum of the "Static Pressure" and the "Velocity Pressure" is the total or dynamic pressure which, as the sum of potential and kinetic energies, per unit volume, is properly enough designated as "Total Pressure." In plotting test results both total and static pressures may be presented. Fig. 1 shows in solid lines typical fan characteristic curves.

The restrictions used in test to get definite points for plotting the curves may be nozzles or orifices of different sizes attached to the end of the duct. Each nozzle determines a definite point on the fan characteristic.

Before discussing the interaction of two fans and system resistance, it may be well to examine a single fan on a system. Any other nozzle, different in size from those used in the actual test, will permit a flow which is determined by the condition that the effective nozzle area times a velocity equivalent to the total pressure must equal the corresponding volume as shown by the total pressure characteristic of the fan. This point on the fan characteristic, to suit the new nozzle, may be determined laboriously by trial and error, or more easily by graphics according to the following procedure:

The volume delivered through the nozzle by a 1 in. total pressure is readily calculated as the pressure becomes velocity at the nozzle mouth. It is well known that four times the pressure will cause a flow of twice the volume; that is, pressure will vary as the square of the volume. A common square parabola plotted on the chart, having its vertex at the origin of the coordinates and passing through the points determined by the cal-

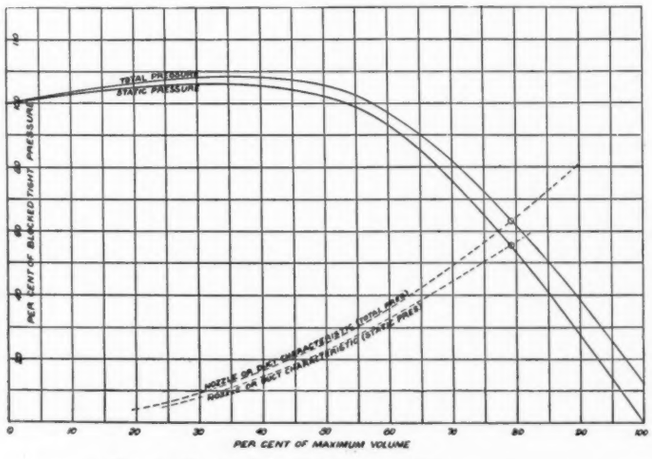


Fig. 1—Typical fan characteristic curves

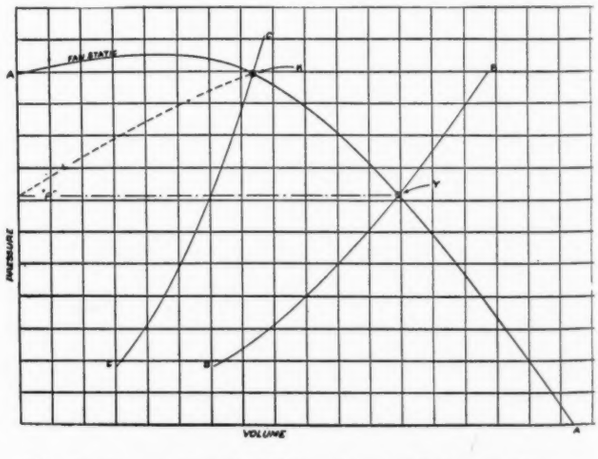


Fig. 2—Conventional plotting for parallel operation

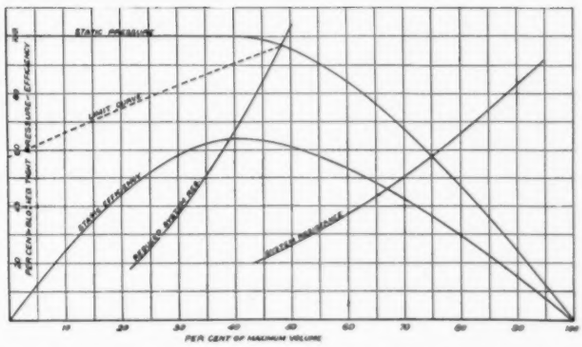


Fig. 3—Characteristics of multi-bladed radial-blade fan

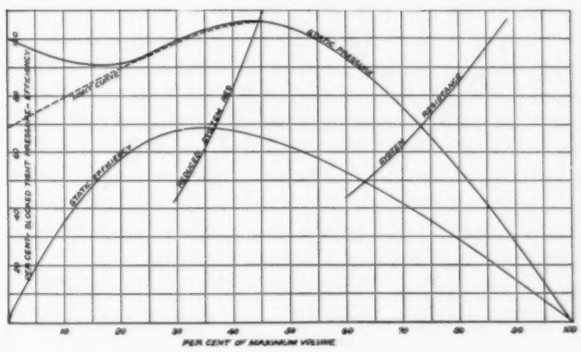


Fig. 5—Analysis applied to forward curved blade fan

culated volume and corresponding 1 in. total pressure plus duct friction, will be the locus of every volume and corresponding pressure that can exist at the fan outlet with that nozzle on the duct. The parabola may be called the nozzle characteristic.

It is apparent that the point at which the fan will operate must lie on the fan characteristic and also satisfy the nozzle characteristic. The fan with this new nozzle will operate at the point of intersection of the nozzle characteristic and the total pressure characteristic of the fan. The dotted line on Fig. 1 is a nozzle characteristic. The nozzle is a simple form of resistance. But any fan load can be represented by a similar curve called the system characteristic, and the point of operation is similarly determined by the point of intersection with the characteristic of the particular fan.

Air-flow problems are readily analyzed and solved by considering the action as dependent upon these intersections, and in no other manner. The characteristics are a complete representation of the physical facts.

It is necessary here to interpolate a discussion of total and static pressures. In the foregoing analysis of fan and nozzle, total pressure was used. Inasmuch as velocity pressure at the nozzle discharge is the same as total pressure ahead of the nozzle, and as this, with an additive duct friction, equals total pressure produced by the fan, the use of total pressure was the simpler. It would have been entirely practicable, however, to determine the static pressure of the system by subtracting from the 1 in. total pressure the velocity pressure in the duct at the calculated volume and add duct friction. A parabola drawn through the point for these values would then cross the static pressure characteristic of the fan at the volume indicated by the total pressures.

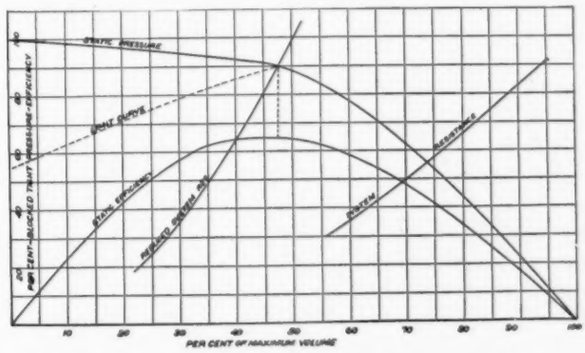


Fig. 4—Characteristics of intermediate type fan having eight radial blades

Paralleling of fans depends on the inter-relation of fan and system characteristics in a manner similar to the action of a single fan and system, and, similarly, may be analyzed from either total or static pressures. Theoretically, total pressure, or the equivalent static plus velocity pressure, should be used when the duct area is of the same order of magnitude as the sum of the areas of the fan outlets. The actual analysis becomes complicated, however, and this complication tends to obscure the underlying principles. Also the results so obtained differ from those based more simply on static only by such small amounts that the more complete analysis including velocity pressure is seldom worth while. Furthermore, fans delivering air to a large area system, such as a closed stokehold or plenum chamber, will parallel on their static characteristics. For these reasons, the main discussion will be limited to static pressures and the general case confined to a brief appendix.

Fig. 2 shows in solid lines the conventional plotting for parallel operation. Curve *AA* is the fan static, curve *BB* the actual system resistance intended for air from two fans and curve *CC* the reduced system resistance or half volume curve applicable to the characteristic of a single fan. The crossing point, *K*, gives the volume and pressure each fan will deliver in perfect parallel operation to satisfy the system curve *BB*. The plotting gives also the point, *Y*, the output if only one fan is running.

It is possible to add to this chart another curve derived from the fan characteristic and the full system characteristic of which the pressure of point *Y* gives the starting point. It is apparent that a different fan having this pressure at zero volume would give a minimum condition in the general problem of parallel operation where one fan handles all the air flowing and the other delivers none. It is also evident that any fan capable of a higher pressure would deliver some air to the duct.

It is a simple graphical construction to lay in the limit curve of parallel operation. At any pressure, *P*, greater than that at *Y*, pick off with dividers the volume intercept between the fan characteristic *AA*, Fig. 2, and the system resistance, *BB*. The volume of this intercept is the additional volume the duct could accept from the second fan at that pressure. Plotted from the origin at pressure, *P*, the point lies on the limit curve. Repeating the process for a sufficient number of points will give curve *LL*. The requirement of parallel operation is that the limit curve shall intersect the fan characteristic determinately and at only one point.

If the two fans are duplicates, the second develops the

pressure of the curve AA, the same as the first. The excess of AA over LL is the indication of the certainty of parallel operation, and the crossing angle gives a suggestion of the determinativeness of action; too small an angle may permit oscillations. This analysis shows that the frequently specified "Rising Characteristic" all the way to zero volume is quite unnecessary. As a matter of fact, pressures in the low volume range are unimportant, and a blocked-tight pressure, even below the operating pressure, may have no effect whatever on successful parallel operation. From the standpoint of power consumption it is fortunate that a continually rising curve is not required as this condition can be secured, with most types of fans, only at a sacrifice of efficiency.

It is interesting to extend the analysis to the form of characteristic shown in Fig. 3, where the pressure curve is flat, and to note that the flat characteristic still has leeway over the limit curve and that the factor of system resistance enters to require a division of load between the fans. A multi-bladed radial-blade fan has a characteristic as shown in Fig. 3.

An intermediate type of fan with eight radial blades is represented in Fig. 4. Customary practice would select the fan to operate just beyond the peak of the efficiency curve as indicated. The area giving certainty of parallel operation is determined in the usual manner and indicates successful operation.

Fig. 5 shows the analysis as applied to a forward curved blade fan of conventional type. While paralleling can be secured with this type by selecting operating pressures well below the peak pressures, it should be noted that high efficiency and successful parallel operation are incompatible.

The analysis can also be used to examine the action of fans operating in parallel at different speeds. For this demonstration the static pressure characteristics of Fig. 1 are reproduced in Fig. 6 with curve SS added, giving the characteristic for a 5 per cent speed reduction. From the manner of drawing the limit curve it is evident that the pressure developed will be given by the intersection of the limit curve and the fan characteristic for the lower speed. Necessarily, the combined volume will be the volume of the system resistance at that pressure with the fans proportioning as shown by their characteristics against that same pressure.

Throughout this discussion the parabolic system resistance has been used. This is the type most often encountered. There are other types of system resistance specified by engineers, but these are almost always the result of a system that is changed physically for a change in volume. A series of oil burning nozzles is an

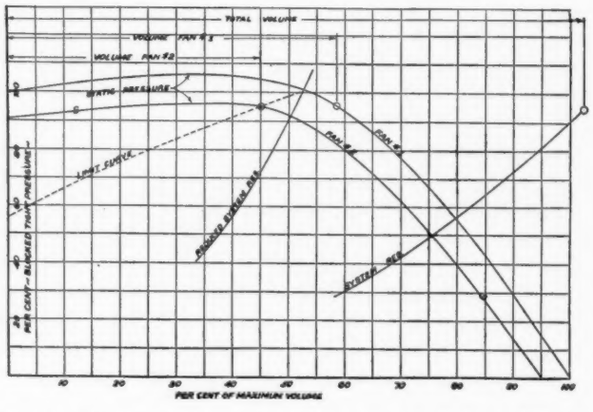


Fig. 6—Curves for fans operating in parallel at different speeds

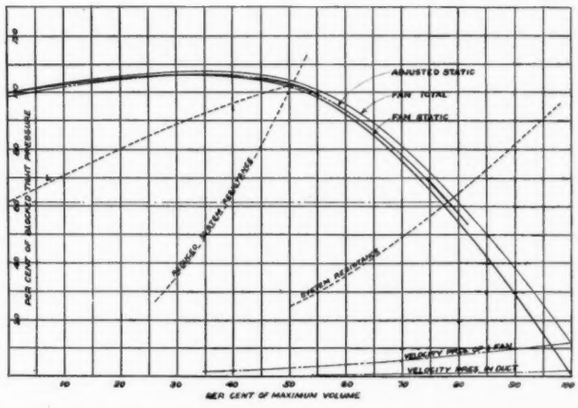


Fig. 7—Chart for general use with duct 20 per cent greater than twice the fan outlet area

example. Larger volumes from the fan are accompanied by the physical change of opening additional nozzles. For such a system pressure requirements for various volumes may be plotted on a chart, but for strict accuracy they should be considered as isolated points of operation. Each point implies a parabolic system resistance curve corresponding to the number of open nozzles. Paralleling, even in this case, will take place along these specific parabolae when the required nozzle arrangement is set and not along the pseudo-characteristic connecting the isolated points. Parallel operation should, therefore, in practically every case, be based on a system curve of constant resistance as has been done in this discussion. However, the graphical constructions are applicable to any form of system resistance or fan characteristic.

APPENDIX

The effect of velocity pressure in addition to static on parallel operation of fans is perhaps best introduced by considering the conversion of velocity pressure differences between fan outlets and system area. The fan static pressure characteristic may then be changed into effective static at the system. The identical analysis already described is then followed using this adjusted static curve with a corresponding limit curve.

Three points on the adjusted static are readily secured.

The first is a corrected value for a single fan operating on the system. The velocity from the single fan outlet is higher than the velocity in the system duct. An increase in static will result from conversion of the higher fan velocity pressure. The efficiency of conversion will depend upon the nature of the transitional flow and probably in most cases will be the action of abrupt expansion. The correction can be calculated for a few volumes in the region and the useful portion of the corrected static drawn in. The intersection of the static system resistance with the new curve will now give one point on the desired adjusted static. An exactly similar procedure will give a second point in the region of the reduced or half volume system curve using the fan outlet area and half this system duct area to figure the static increase. In the special case where duct area is twice the fan outlet area the correction is zero.

The third point is at zero volume and is below the fan static by the system velocity pressure of the first point—that is, the velocity pressure in the system duct for the corrected volume of the single fan operation. The location of this third point becomes self-evident if, instead of a zero volume, a differential volume is considered. It is clear that the second fan must provide even a differential volume with the velocity pressure required by the system, and that this velocity pressure must be supplied from the fan static.

With the guidance of the original fan characteristic and the three special points the desired adjusted static can be drawn in accurately enough. However, additional points can be calculated by trial and error assuming a virtual appropriation of system duct area by each fan; one fan working on an increased area and the other on a decreased area. The labor of calculating such intermediate points is waste effort in most cases. The lack of exact knowledge of conversion efficiencies, and the smallness of the corrections involved, hardly warrant considering velocity changes at all, and certainly to no greater exactness than is given by the three special points.

Fig. 7 shows the complete chart for the general case with a common duct 20 per cent larger than twice the fan outlet area. Conversion efficiencies are those of abrupt expansion.

Modernizing the Conners Creek Power Plant—VI

Piping (Part 2)

By SABIN CROCKER
Engineer, The Detroit Edison Company

In the March installment of this series the pipe welding procedure was outlined; the present article deals with the piping layout, the piping materials selected, supports and valves. The concluding article, to appear in the May issue, will give an account of retubing the old condensers to serve larger units, will discuss the deaeration of condensate, chlorination of circulating water and feedwater heaters, and will give operating performance together with a tabulation of equipment in the rebuilt plant.

THE problem of making satisfactory piping layouts for the rebuilt plant was complicated by space limitations imposed by the existing building arrangement and the necessity of installing additional equipment to care for the needs of a modern plant. This additional equipment comprises: extraction feedwater heaters for the main units, direct-current house-service units with their condensers and auxiliaries, economizers, air preheaters and zoned air-control apparatus. The feedwater pumping equipment and the draft equipment are greatly increased in size and capacity over the old equipment.

In the old plant, the bulk of the steam and feedwater piping was located in rather cramped quarters under the boiler-room operating floor. The greater expansive movement of the higher temperature piping in the rebuilt plant, with its attendant problem of securing adequate flexibility, require an entirely different location for the piping. The boiler leads are carried up and along the boilers to the turbine room wall.

Main Superheated-Steam Piping

An examination of the superheated-steam piping layout reveals rather definite departures from the principles which governed the layout of similar piping in the last plant constructed by The Detroit Edison Company. Sketches illustrating the ring-header system at Delray No. 3 and the system installed in the rebuilt Conners Creek Plant are given in Figs. 53 and 52, respectively. The Conners Creek main-steam system shows a partial

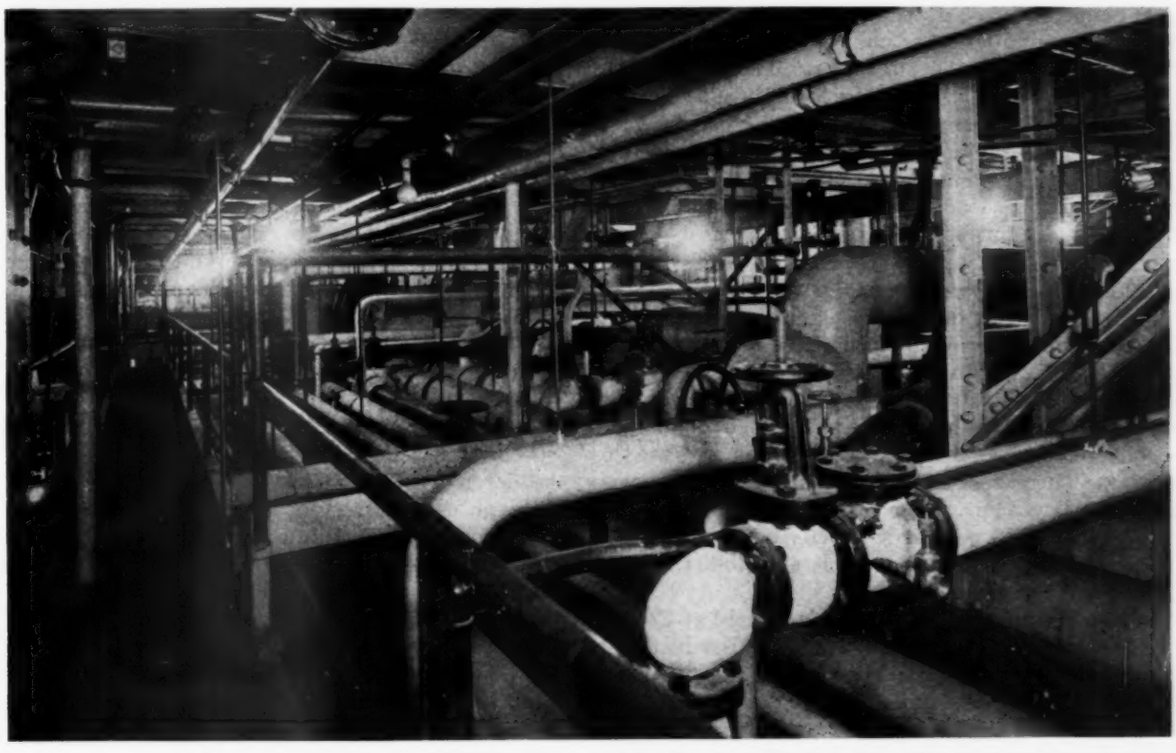


Fig. 51—Piping in condenser room as viewed from valve access walk-way

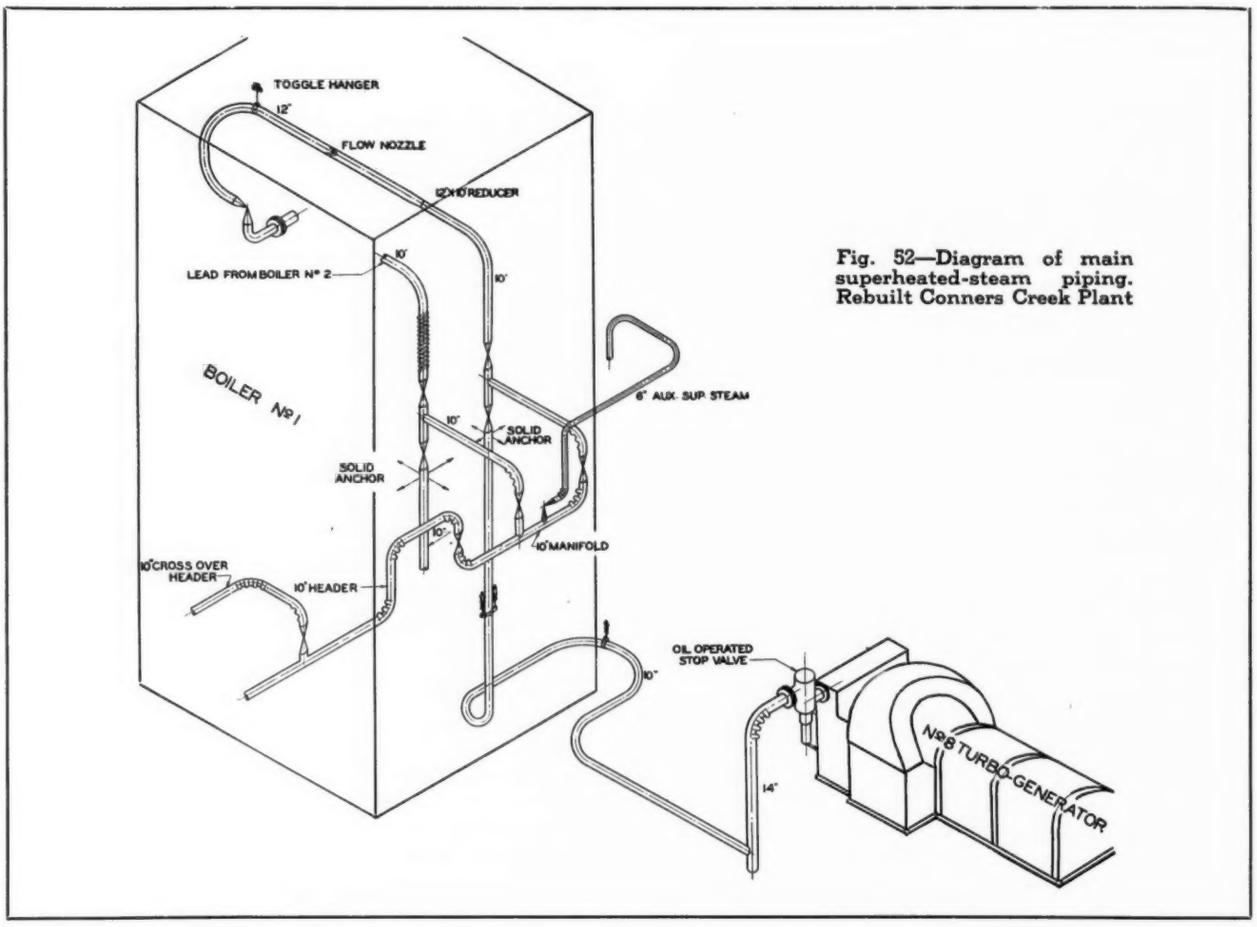


Fig. 52—Diagram of main superheated-steam piping. Rebuilt Conners Creek Plant

approach to the unit boiler-turbine plan in that each boiler, or two boilers in the case of the 60,000-kw units, is direct-connected to a turbo-generator. The steam from each pair of boilers, may, however, be by-passed through a 10-in. header to the turbine connected to adjacent boilers or even to successive units farther down the line. Normal throttle pressure can be maintained when steam is interchanged between boilers of one battery, but some reduction in throttle pressure under full turbine load results when steam is furnished from more distant boilers. In a recent test, it was found possible to secure full rated output of the first two 30,000-kw units when supplied with steam from the adjoining battery of boilers through the loop shown in Fig. 52. While the pressure drop from boiler to turbine throttle under this abnormal condition was more than three times that for usual service conditions, the ability to supply these turbo-generators in the event of outage of the direct-connected boilers was fully demonstrated by the test. The main steam system installed at Conners Creek is believed to combine the advantages of low pressure drop and general simplicity of the unit boiler-turbine system with the greater availability of the interconnecting header system.

Some of the advantages of the layout used at Conners Creek over that at Delray No. 3 are: (1) reduction in pipe size of boiler leads and cross-over, (2) reduction in length of pipe required and (3) reduction in number of valves. The saving in valves over the loop-header system is perhaps the most noteworthy improvement as the number has been cut almost in half. The use of one stop-check valve per boiler in place of two as at Delray No. 3 was an economy incidental to the design of the constant-temperature superheater which was described in the January installment on "Boilers and Steam Generating Equipment."

Boiler and turbine stop valves, and header-division valves are motor operated from a remote control station located near the plant engineer's office. Valves are closed electrically, but, in accordance with established practice of the Company, they must be opened by hand. Opening these valves by hand is considered desirable so that the operators can observe the pressure gages on both sides to insure equalizing the pressure when placing a line in service. This also tends to reduce the possibility of opening a valve by mistake.

Boiler-feed Piping

The layout of one section of boiler-feed piping is shown schematically in Fig. 54. It consists of a single ring-header fed through risers which enter the ring-header between each battery of boilers. Sectionalizing valves are provided, which, in combination with the ring-header, enable water to be fed a boiler in the event of piping difficulty in a riser or portion of the header normally used to supply that boiler. Past practice of the Company has required duplicate systems of feedwater piping including separate connections to the boiler drums, but the need for the auxiliary-feed system has become less evident as the dependability of piping construction and materials has increased. An extensive study of the reliability of boiler-feed systems in the

Company's other plants demonstrated that since no real emergency had occurred to require the use of a dual-supply system, such extensive duplication could not be considered essential. On the other hand, due to the high degree of reliability expected of a boiler-feed system, it was deemed unwise to depend entirely on a single line of supply all the way from pump to boiler. Hence a compromise design was evolved using a single riser from the pumps of each main unit to approximately boiler drum level. At this elevation a ring-header system extending around the boilers is provided as shown in Fig. 54. This ring header collects all the pump risers and affords two paths for water to reach the feed connections of each boiler. In addition to eliminating a certain amount of parallel piping, this simplification effected a considerable reduction in the number of valves required, both at the pump discharge and the boiler drums. A comparison of the boiler-feed connections to the boiler drums as used at Conners Creek and Delray No. 3 is given in Fig. 55. In addition to other savings, the number of valves required for the Conners Creek feed connections between header and drum is only about two-thirds of the number at Delray No. 3 and the former plants. An incidental advantage in eliminating the auxiliary-feed system is the saving in heat loss chargeable to keeping the emergency line hot, as is done in other plants by continuously bleeding a small amount of hot water back to storage.

The boiler-feed risers and ring headers were designed for a water velocity of ten feet per second under normal maximum-flow conditions, which was considered about the top velocity consistent with safe design. An investigation at one of the Company's other plants of water hammer actually produced at different water velocities through sudden closure of a valve or tripping out of a boiler-feed pump, showed that velocities in excess of about ten feet per second produced shock pressures greater than deemed permissible without increasing the pressure-rating standard of the line. While velocities up to fifteen or even eighteen feet per second appear from numerous studies to be economically justified from the standpoint of pumping cost, better methods for minimizing the effect of water hammer are required before such velocities are used.[1]

Dimensional Standards and Materials for 850 F Service

Since questions of dimensional standards are inextricably bound up with the character of materials used, the thickness of pipe wall, the allowable bending stress and the pressure standard of valves will be discussed in connection with materials. Inspection of pipe and valves to assure that they live up to expectations as to dimensions and material will also be described.

Pipe

One of the first problems investigated was the material to be used for 850-F steam lines. A number of short-time tensile and creep tests was made at 850 F on Grade A, low-carbon and Grade B, medium-carbon pipe, conforming to A.S.T.M. *Spec.* A106. From these tests it was concluded that a silicon-killed, medium-carbon steel of the following analysis would be suitable for 850-F service:

[1] See, "Economical Boiler Feedwater Piping Design," by Geo. F. Campau, *Power Plant Engineering*, November 1933.

COMPOSITION OF PIPE MATERIAL

Carbon, per cent	0.35 max
Manganese, per cent	0.75 min
Silicon, per cent	0.15 min
Metallic aluminum, per cent	0.06 max
Sulphur	0.06 max
Phosphorus	0.04 max

In selecting the wall thickness of pipe for 650 lb per sq in., 850-F service, the first consideration was, of course, that the bursting stress should not cause an objectionable increase in diameter and consequent thinning of the pipe wall within the expected life of the equipment. On the basis of available creep data, an allowable bursting stress of 7000 lb per sq in. was assumed. The resulting wall thicknesses were found to conform sufficiently close to Schedule 80 of the table included in A.S.T.M. *Spec.* A106-34T.[2] Schedule 80 pipe, which in pipe sizes 8 in. and smaller corresponds to "extra strong" pipe thickness, was selected for all superheated-steam services. A comparison of the specified physical properties of this pipe with those actually obtained on test is given later in the present article.

Aside from the additional cost of pipe with a thicker wall, which might have been considered necessary if low-carbon pipe material were used, the increase in rigidity of a line using the heavier pipe would have been a very definite disadvantage from the standpoint of securing adequate flexibility. Adequate flexibility not only implies safe fiber stresses but also that the reacting forces and bending moments set up by thermal elongation are kept within suitable limits. These limits are established by permissible thrusts on turbines and building steel and allowable bending moments in the pipe and at bolted and welded joints. In the case of the

[2] *Proceedings* of the American Society for Testing Materials, Part I, Vol. 34, 1934, p. 642.

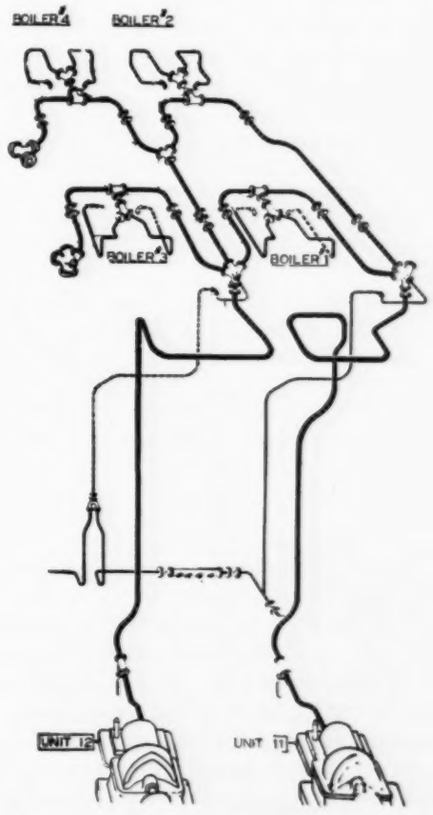


Fig. 53—Diagram of main superheated-steam piping, Delray No. 3 Plant

30,000-kw units, the thrust on the turbine steam chest was limited to 800 lb by the turbine manufacturer. This figure was increased to 2500 lb for the 60,000-kw unit as being a more reasonable requirement. The computed thrusts, without taking credit for reduction due to initial cold spring, are well below these allowable thrusts.

For purposes of design the maximum allowable stress due to bending plus longitudinal pressure was established at 15,000 lb per sq in. for smooth bends and pipe removed from bolted and welded joints. The allowable stress was limited to 10,000 lb per sq in. in pipe adjacent to creased bends, corrugated tangents and bolted and welded joints. It should be noted in considering these allowable stresses that a distinction can properly be made between stress caused by constraint of thermal elongation, which may relieve itself of an overburden through creep, and stress due to internal pressure which is either constant or tends to increase with time.

The reduction in reacting forces and moments, which is obtainable with short-radius bends, led to the rather general use of creased bends made with a center-line radius two times the pipe diameter. It was also found expedient to insert a corrugated filler in the vertical leg of the boiler lead to the further removed boiler in each battery as shown in Fig. 52. The use of a super-flexible element in this location enables both near and distant boiler leads to be placed at the same elevation.

Hangers and Supports

In order to isolate expansive movement of the boiler leads from the turbine leads, rigid anchorages were provided at the turbine stop-valves which are located near the header. These anchor points for Units 8 and 9 also are shown in Fig. 52. Because of the large vertical movement of the boiler leads from the cold to the hot position amounting to approximately 4 in., toggle hangers were used to maintain a nearly constant vertical support for the line. The toggle hanger, shown in Fig. 56, is designed to support a load of 1200 lb with a change in load from the cold to the hot condition of only 100 lb. Adjustable sway braces, or vibration dampeners, are installed which enable necessary restraint to be placed on the line. A group of these sway braces is shown in Fig. 57 The turbine leads are supported with simple spring hangers which suffice where the vertical movement is not too great.

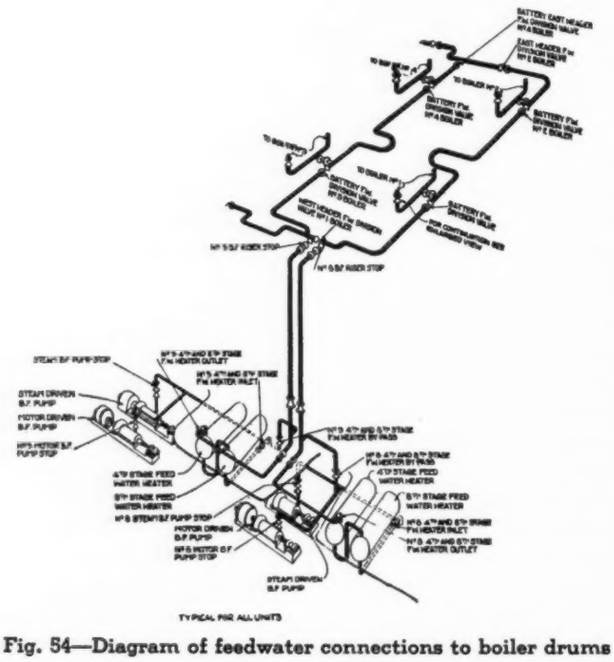


Fig. 54—Diagram of feedwater connections to boiler drums

Valves

Before selecting superheated-steam valves the manufacturers were asked to submit their recommendations as to materials for use in 850-F service. As experience in casting a particular analysis was believed to be fully as important as the analysis itself for service at 850 F, no effort was made to specify the type of alloy to be used in valve bodies by the different manufacturers. Instead a rather extensive investigation was undertaken to determine the weldability and general acceptability of the castings offered by the manufacturers whose valves were otherwise approved.

Sample cast cylinders of the analyses recommended for valve bodies were welded to lengths of silicon-killed carbon-steel pipe. Short-time tensile, creep and impact tests were made on specimens cut from different parts of the weld.[3] As a result of these tests, an alloy was selected in which the content of each of certain alloying elements was henceforth specified as the maximum allowable, whereas it had originally been established as the lower limit of an acceptable range. This reduction in alloying content was made to reduce the air-hardening tendency and to secure greater ductility in the cast material.

The composition and physical properties of the material specified for bodies of parallel-slide gate valves and the stop-and-check valves of the three 30,000-kw and the first 60,000-kw units are tabulated below. The carbon-molybdenum cast steel described under "Boiler Feed" is also considered acceptable for this service.

COMPOSITION AND PHYSICAL PROPERTIES OF NICKEL-CHROME-MOLYBDENUM CAST STEEL

Chemical Composition		Physical Properties (min)	
Carbon, per cent	0.28 max	Tensile strength, lb per sq in.	85,000
Manganese, per cent	0.70 max	Yield point, lb per sq in.	60,000
Nickel, per cent	1.05 max	Elong, 2 in., per cent	20
Chromium, per cent	0.70 max	Reduction of area, per cent	35
Molybdenum, per cent	0.40 max		
Silicon, per cent	0.25 min	Charpy V-notch, ft-lb	30
Phosphorus, per cent	0.05 max		
Sulphur, per cent	0.05 max		

All valves $2^1/_2$ in., and larger, in superheated-steam lines were made with butt-welding ends tapered to within $^1/_8$ in. of the outside pipe diameter. End-to-end dimensions, body thicknesses and other dimensions conform to the American Standard for 900-lb S.S.P. in sizes 3 in. and larger and to the American Standard for 1500-lb S.S.P. in the smaller sizes.

TRIM: Seat-rings for the parallel-slide gate valves in the 850-F steam lines in the first section were bottom-seated screwed rings of a copper-nickel-tin alloy, while disks were made of a free-machining variety of stainless steel.

No difficulty has been experienced with this combination of seating materials in a little over one year's service at 850 F. However, leakage around screwed seat rings at other plants, as well as favorable experience with valve seats faced with "stellite" led to the adoption of

[3] "An Examination of Welds Made under Field Conditions for High Pressure, High-Temperature Steam Station Piping," by A. E. White, D. H. Corey and C. L. Clark, *Journal of the American Welding Society*, September 1934.

stellited seat-rings welded to the body for valves in the subsequent sections of the plant. Disks are cast-carbon steel faced with "stellite."

BONNET BOLTING: A chrome-tungsten bolting material has been supplied in bonnet joints of valves $2^1/_2$ in. and larger for 850-F service. This bolting material, which conforms to requirements for Class C bolting of A.S.T.M. *Spec.* A96, has better creep resistance at 850 F than the chrome-nickel material used for 700-F service in the Company's plants.

BONNET GASKETS: Corrugated stainless steel, corrugated monel and smooth soft-iron gaskets were used in the bonnet joints of the valves supplied by the different manufacturers for 850-F service. A year's use has not disclosed any advantage of one gasket material over another as all have been satisfactory with the narrow gasket surface employed in valve-bonnet joints.

Inspection of Piping Materials

Inspection of important materials and equipment at the manufacturer's plant is a routine matter which is part of the purchasing set-up of the Company. In the inspection of pipe and valves for 650-lb, 850-F service, however, this inspection was made more rigorous than usual, with comprehensive tests for checking the acceptability of the material. Inspection of piping materials for boiler-feed and other high-pressure services was no less careful although the inspector was not required to witness the various fabrication processes to the same extent.

Pipe 3 in., and larger, intended for 850-F service was tested in accordance with the supplementary requirements for power-plant piping of A.S.T.M. *Spec.* A106, except for the omission of individual chemical analysis of each length of pipe. While these supplementary tests entail an increase in the cost of pipe, the greater assurance of securing satisfactory material is considered ample justification for the tests. For the lower-temperature high-pressure lines, the supplementary tests were confined to pipe 8 in. and larger.

These supplementary tests which among other things require a tensile test on each end of the pipe, have revealed that one end of a 30-ft length of seamless pipe may be much less ductile than the other. In most instances, the specified elongations have been obtained after cropping back a few feet, but in one case some 3-in. hot-rolled pipe had to be annealed to meet the specified elongation. The etch test made on the flattened ring from one end of each pipe has thus far disclosed evidence of unsatisfactory structure in only one instance.

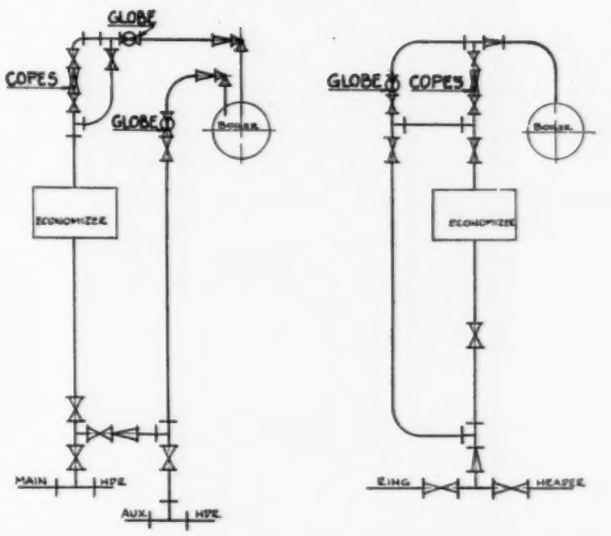
A few lengths of pipe have been rejected or cropped back further on account of gougings or slivers. The practice of shot-blasting the inside of high-grade pipe is deemed a useful aid to the inspector in locating such defects.

The superior quality of the pipe material may be appreciated by comparing the physical properties obtained on 0.30 per cent carbon pipe material with the minimum physical properties specified for Grade B pipe of A.S.T.M. *Spec.* A106.

COMPARISON OF PHYSICAL PROPERTIES OF PIPE MATERIAL

	Specified Grade B A106	Typical Avg 17 pieces
Tensile strength, lb per sq in.	62,000	88,000
Yield point, lb per sq in.	35,000	68,000
Elongation 2 in., per cent	20	30

The average tensile properties obtained on specimens from separately cast and integrally cast test bars representing alloy castings for superheated steam service are compared below with the minimum properties specified.



Delray P. H. No. 3 Total No Valves-16 — Conners Creek Sec. "A" Total Valves-11

Fig. 55—Comparison of feedwater connections to boiler drums, Delray No. 3 and Conners Creek

COMPARISON OF PHYSICAL PROPERTIES OF VALVE-BODY MATERIAL CHROME-NICKEL-MOLYBDENUM CAST STEEL

	Specified	Average 28 Castings Separately Cast Specimens	Integrally Cast Specimens
Tensile strength, lb per sq in.	85,000	91,000	89,800
Yield point, lb per sq in.	60,000	61,300	61,200
Elong 2 in., per cent	20	23.7	23.3
Reduction of area, per cent	35	50.5	47.9
Charpy, V-notch, ft-lb	30	33.3	30.9

An examination of the above physical properties and those obtained on the pipe shows that both materials have practically the same room-temperature physical properties. In addition to the usual tensile and ductility tests the impact resistance of one or more specimens representative of each valve body was determined with a Charpy machine using A.S.T.M. standard V-notch specimens.

Valve-body and valve-bonnet castings were subjected to the regular hydrostatic shell test of 2000 lb per sq in. for a 900-lb valve. Disk and seat rings were tested for tightness to 1350 lb per sq in. Tank water at ordinary room temperature was used for testing. No chipping out or welding of defects was permitted before submission to the inspector. Superficial defects were then repaired by welding. All such welding was done prior to heat treatment.

DIMENSIONAL STANDARDS AND MATERIALS FOR BOILER-FEED AND OTHER HIGH-PRESSURE LINES

In general the dimensional standards for pipe and valves intended for boiler-feed and other high-pressure services are the same as for superheated-steam lines. The special analysis silicon-killed pipe material developed for 850-F lines was used for boiler-feed and other high-pressure services because certain advantages in purchasing and inspection accrued from making all such pipe to the same specification. The pipe-wall thickness corresponds to Schedule 80 of A.S.T.M. *Spec.* A106–34T.

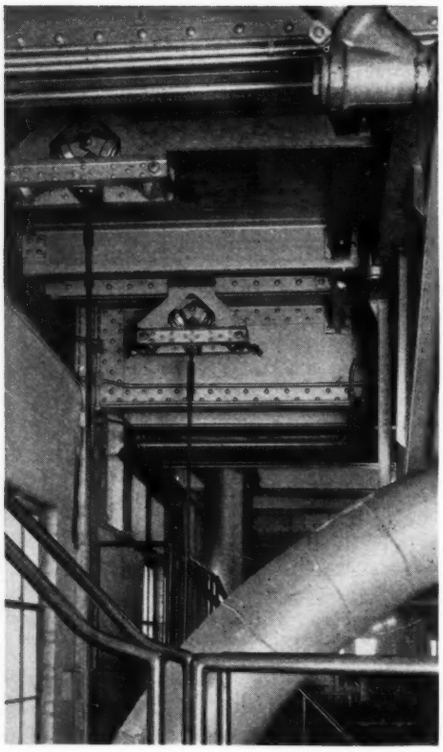


Fig. 56—Toggle hangers, main steam leads from boilers

as in the case of pipe for the superheated-steam lines. The higher working pressure of the boiler-feed lines was found to balance the increase in strength of the material at the lower operating temperature, and so the same pipe-wall thicknesses were indicated.

Carbon-cast-steel valve bodies were used for boiler-feed and other high-pressure services in the first two sections of the rebuilt plant. In the third section, carbon-molybdenum castings were substituted although there was no indication but that carbon cast-steel was adequate for the purpose. The substitution of the carbon-molybdenum alloy was approved partly in order to obtain some practical experience with this type of casting alloy which has won recent favor because of its superior creep strength at temperatures around 900 F, and partly because the use of welding-end valves had been extended to include boiler-feed valves and the higher room-temperature physical properties of the carbon-molybdenum material were regarded as additional assurance that the tapered section at the ends of the valve body would be amply strong.

The composition and physical properties of the material specified for bodies of the wedge-gate valves for boiler-feed lines in the third section of the rebuilt plant are tabulated below.

COMPOSITION AND PHYSICAL PROPERTIES
CARBON-MOLYBDENUM CAST-STEEL VALVE BODIES

Chemical Composition		Physical Properties (min)	
Carbon, per cent	0.20–0.35	Tensile strength, lb per sq in.	70,000
Manganese, per cent	0.70–1.00	Yield point, lb per sq in.	50,000
Molybdenum, per cent	0.40–0.60	Elong, 2 in., per cent	20
Silicon, per cent	0.30–0.50	Reduction of area, per cent	35
Phosphorus, per cent	0.05 max	Charpy, V-notch, ft-lb	25
Sulphur, per cent	0.05 max		

Valves 3 in. and larger conform to the American Standard for 900-lb S.S.P.; valves $2^1/_2$ in. and smaller, to the American Standard for 1500-lb S.S.P. Flanged-end valves have $^1/_4$-in. standard raised faces. Seat-rings for wedge-gate valves are a copper-nickel-tin alloy; disks are stainless steel of the 12 to 14 per cent chromium type. Globe valves and piston-check valves have approximately the same combination of seating materials. Chrome-nickel bolting material conforming to A.S.T.M. *Spec.* A96, Class C, was supplied with the valves. Corrugated stainless steel and corrugated monel gaskets were supplied in the bonnet joints of the boiler-feed valves for the first sections. In the third section in addition to these gasket materials, a soft-iron gasket ring is being provided for the special "ring type" of bonnet joint featured by the manufacturer supplying the carbon-molybdenum valve bodies.

Miscellaneous Piping Systems

The low-pressure-piping systems of any modern power plant embody details of design which are of interest to those engaged in making such piping layouts. But aside from the use of welding, there is nothing particularly novel in this piping in the rebuilt Conners Creek plant unless it is the utilization of existing systems and the salvaging of material from the old piping. Brief mention of those systems not otherwise covered in this or preceding installments is made in the following paragraphs.

General-service water constitutes one of the essential services of a power plant, involving as it does fire protection, operation of hydraulic valve operators, cooling of transformers and fan bearings and a multitude of miscellaneous services such as makeup to evaporators, spraying clinkers and washing screens and condensers. River water is taken from the intake canal by either steam- or motor-driven pumps and discharged at about 100 lb pressure into ring headers in the boiler and turbine room basements. Careful estimates have been made of probable demand for general-service water at various steps in the rebuilding program, and pump capacity planned accordingly.

Saturated steam at about 250 lb per sq in. is used for a number of purposes throughout the plant, among which are: to seal turbine shaft packing; to drive turbine-driven general-service water pumps; and to operate the jets of the air ejectors on auxiliary condensers. It also serves as standby for building heating when insufficient bled steam is available from the direct-current house-service units, and for fire extinguishers on main generators.

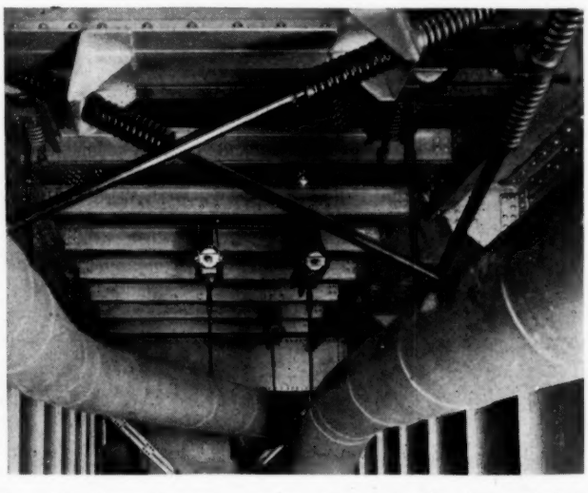


Fig. 57—Sway braces, main steam leads from boilers

PENNSYLVANIA BITUMINOUS COALS— Their Classification and Analyses

By P. B. PLACE
Combustion Engineering Company, Inc.

Previous articles of this series have dealt specifically with Ohio, Kentucky, Virginia, Illinois and Indiana coals, as well as an introductory article surveying broadly coals of the United States. In each the author traces individual seams through various counties and states, gives their characteristics and identifies them by county or trade names. The next article will discuss the medium- and low-volatile coals of Pennsylvania.

Description of Bituminous Fields

THE bituminous coal fields of Pennsylvania underlie some fourteen thousand square miles in the western part of the state and contribute about a quarter of the bituminous production in the United States. The coal industry in Pennsylvania has been highly developed and is by far the most important industry in the state. For many years this state has led all others in the production of bituminous coal and has drawn heavily on its developed areas of high-grade fuels. In recent years West Virginia has taken the lead in the bituminous field but Pennsylvania has large reserves as yet undeveloped and will continue to be one of the leading producers for many years to come. The present rate of production of bituminous coal in Pennsylvania is on the order of 150 million tons per year and estimates of the period over which this rate of production may be economically maintained varies from seventy to two hundred years.

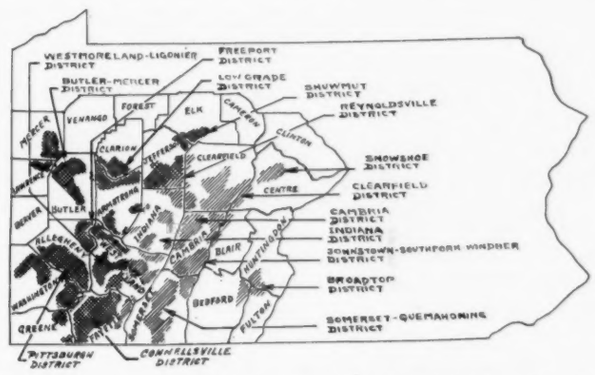
Table I gives the relative production of bituminous coal in the principal producing counties in Pennsylvania during recent years. Formerly Fayette and Westmoreland counties were the largest producers but the principal seam, the Pittsburgh, is approaching exhaustion in these counties. As seen in Table I sixty-five to seventy per cent of the total production comes from five counties, Allegheny, Cambria, Washington, Fayette and Westmoreland. Although in many of these counties the developed seams are being exhausted, all of the counties have large reserves that will be developed to maintain the present large production rate in the state.

The bituminous region has a number of active mining districts which have been variously named. Three classifications of these districts, as given in the Keystone Coal Buyers Manual, are given in Table II.

TABLE I

Relative Production of Bituminous Coal in Principal Producing Counties 1929 - 1932

County	1929	1930	1931	1932
Allegheny	11.6	13.5	14.6	15.7
Cambria	12.2	12.8	13.6	14.5
Washington	13.5	14.1	14.0	14.0
Fayette	21.9	19.2	14.3	11.2
Westmoreland	12.0	11.4	11.6	11.1
Somerset	6.2	6.5	7.6	7.4
Indiana	5.7	6.2	7.0	7.4
Greene	4.4	4.1	3.8	4.2
Clearfield	2.8	2.8	3.2	3.5
Armstrong	3.1	2.8	2.9	3.1
Jefferson	1.8	1.9	2.1	2.3
	95.2	95.3	94.7	93.6



Bituminous coal-producing areas of Pennsylvania and principal mining districts

The coals mined in the bituminous region in Pennsylvania range from soft, low-volatile smokeless fuels in the central part of the state to the harder high-volatile gas coals in the western part. In general, the volatile increases progressively from east to west, low-volatile fuels coming from Cambria and Somerset counties, medium-volatile fuels from Indiana and Clearfield counties and high-volatile fuels from Allegheny, Washington, Fayette, Armstrong, Westmoreland and Greene counties. County lines cannot, of course, be expected to mark sharp changes in the volatile content of the coals mined in these areas and in many cases there is found a considerable variation in the volatile matter within a single county. Thus, Cambria and Somerset counties produce medium-volatile coals as well as low-volatile and Fayette and

Westmoreland counties produce medium-volatile coals as well as high-volatile.

Some fifty or more coal beds have been identified in the two to three thousand feet of coal-bearing rock in the bituminous region. For purposes of classification these rocks are divided into so-called groups or formations representing certain periods of time. Table III gives the geological classification of the coal-bearing rocks and the principal coal seams listed in the order in which they are found. Each division represents a period of time and the position of a bed in the table is an indication of its relative age. Thus, the Freeport and Kittanning seams in the Allegheny group are older than the Pittsburgh seam in the Monongahela group and more deeply buried.

A coal bed is a relatively thin layer laid down over a wide area and represents a period of organic growth. It is believed that the coal beds in Pennsylvania were originally laid down on fairly level ground that was slowly sinking below sea level. During periods when the land was not submerged the organic growth accumulated somewhat as it does in present-day swamps. Between these periods the land was submerged and slowly covered by mineral mud washed in by rivers and tides. After laying down these alternate strata of peat and dirt for many years the whole area was subjected to a horizontal thrust from the east that compressed the mass and upheaved the Allegheny ridge. The organic strata were partially dehydrated and carbonized by the heat and pressures developed during this period and transformed into our present coal deposits. That the action was greater in the east is indicated by the progressive change in volatile from the anthracite deposits in eastern Pennsylvania to the gas coals in the western part of the state.

Much of the upper layers of the original mass has been worn away by erosion. In central Pennsylvania most of the Monongahela group has weathered away and all of the producing seams are from the Allegheny group. On the other hand, in Greene and Washington counties in the southwestern part of the state, the coals of the Washington group are still available, the Pittsburgh of the Monongahela group constitutes the bulk of the production and the coals of the Allegheny group are so deeply buried that little is known about them.

Although there are over fifty bituminous seams in Pennsylvania, only five, the Pittsburgh, Upper and Lower Freeport and Upper and Lower Kittanning, are of primary importance. The Waynesburgh, Sewickley, Redstone, Brookville, Clarion and Middle Kittanning are of local importance. Some of these seams extend into adjacent states and are important producers under different names. Thus, the Pittsburgh seam is mined extensively in Ohio where it is known as No. 8, and in the Georges Creek district in Maryland where it is known as Big Vein. Similarly the Middle Kittanning is the noted Hocking Valley coal of Ohio.

Because of the depth of the coal and the unusual stresses to which the terrain was subjected during the formation of the beds, the composition and character of any one seam is not constant throughout the total field nor are the several seams mined in the same county always similar. Thus, the Upper Freeport seam is a low-volatile coal in the Broad Top area, is both a low and medium-volatile coal in Cambria county, a medium and high-volatile coal in Westmoreland county and a high-volatile coal in Allegheny county. The composition for different seams mined in the same district or limited area are much more likely to be similar than for the same seam mined in different counties.

TABLE II

Bituminous Mining Districts in Pennsylvania

Pittsburgh	Avella Panhandle	Pittsburgh
Connellsville	Connellsville Coking Connellsville Steam	Connellsville Klondike
Westmoreland-Ligonier	Greensburg Latrobe Ligonier Youghiogheny-Westmoreland	Greensburg Latrobe Youghiogheny
Freeport	Conemaugh Thick Freeport	Allegheny River
Butler-Mercer	Butler-Mercer	Allegheny River
Blossburg	Reynoldsville	Blossburg
Broad Top	Broad Top	Broad Top
Somerset	Southern Somerset	Meyersdale Quemahoning-Somerset
Central Pa.	Barnesboro Blacklick Clearfield Monty-Glo Reynoldsville South Fork	Cambria Clearfield Indiana Johnstown Low-Grade Div. Reynoldsville Shawmut Snowshoe So. Fork-Windber Two Lick

TABLE III

Geological Classification of Principal Coal Bearing Rocks, and Principal Coal Seams in Pennsylvania

I. Lower Permian or Dunkard Series
   a. Washington Group
      1. Washington seam
      2. Waynesburgh A seam

II. Upper Pennsylvania Series
   a. Monongahela Group
      1. Waynesburgh seam
      2. Uniontown seam
      3. Sewickley seam
      4. Redstone seam
      5. Pittsburgh seam

   b. Conemaugh Group
      1. Little Pittsburgh seam
      2. Wellersburg seam
      3. Barton seam
      4. Harlem seam
      5. Bakerstown seam
      6. Brush Creek seam
      7. Mahoning seam

   c. Allegheny Group
      1. Upper Freeport seam
      2. Lower Freeport seam
      3. Upper Kittanning seam
      4. Middle Kittanning seam
      5. Lower Kittanning seam
      6. Scrubgrass seam
      7. Clarion seam
      8. Brookville seam

   d. Pottsville Group
      1. Mercer seam
      2. Quakertown seam
      3. Sharon seam

TABLE IV Typical Individual Analyses of High-Volatile Coals in the Principal Producing Counties

I. Pittsburgh Coal

As Received		Moisture and Ash Free							
Moisture	Ash	Volatile Matter	Fixed Carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu/lb
Allegheny County									
2.7	6.3	39.6	60.4	1.5	5.5	84.4	1.6	7.0	15,180
2.0	5.7	39.6	60.4	1.3	5.6	84.1	1.7	7.4	15,070
3.9	6.0	37.9	62.1	1.6	5.6	84.0	1.6	7.2	15,000
Washington County									
2.7	6.9	38.3	61.7	1.5	5.5	84.7	1.7	6.6	15,090
2.7	8.4	39.4	60.6	1.9	5.5	84.0	1.8	6.8	15,100
2.7	7.8	37.5	62.5	1.4	5.4	85.1	1.7	6.4	15,130
Greene County									
2.6	6.7	38.5	61.5	1.3	5.5	85.0	1.7	6.5	15,130
3.0	5.9	38.7	61.3	1.1	5.5	85.3	1.9	6.2	15,170
2.2	7.3	39.7	60.3	2.7	5.6	84.6	1.7	5.4	15,160
Fayette County - Uniontown - Connellsville District									
1.6	8.1	36.0	64.0	1.2	5.6	85.6	1.7	5.9	15,330
2.9	6.2	34.0	66.0	1.1	5.5	85.5	1.9	6.0	15,280
3.5	6.2	35.5	64.5	0.9	5.4	85.7	1.8	6.2	15,290
Fayette County - Monongahela River District									
2.6	7.8	39.2	60.8	2.6	5.6	84.7	1.7	5.4	15,290
2.5	8.2	40.0	60.0	2.0	5.5	85.3	1.7	5.5	15,290
3.7	6.6	38.9	61.1	2.6	5.6	83.9	1.7	6.2	15,190
Westmoreland County									
3.9	5.5	37.1	62.9	1.4	5.5	84.1	1.7	7.3	15,060
3.4	8.4	37.4	62.6	1.6	5.5	84.8	1.7	6.4	15,180
3.4	8.0	37.4	62.6	1.4	5.6	84.6	1.8	6.4	15,150

II. Upper Freeport Coal

Allegheny County									
2.1	10.7	39.4	60.6	1.5	5.7	85.0	1.6	6.2	15,110
2.1	6.7	40.7	59.3	3.2	5.7	84.8	1.6	4.7	15,260
2.6	7.0	39.0	61.0	1.1	5.8	84.7	1.7	6.7	15,140
Fayette County - Connellsville - Tyrone District (North)									
2.1	13.0	36.5	63.5	2.9	5.6	84.6	1.6	5.3	15,260
2.3	6.8	37.3	62.7	2.4	5.5	85.1	1.6	5.4	15,270
Westmoreland County - Irwin District (West)									
2.7	7.9	38.9	61.1	4.0	5.6	84.1	1.5	4.8	15,350
2.4	8.0	39.4	60.6	2.3	5.7	84.1	1.6	6.3	15,180
1.7	8.1	39.2	60.8	1.6	5.7	84.6	1.8	6.3	15,240
Armstrong County									
3.6	6.6	39.3	60.7	1.9	5.6	84.3	1.6	6.6	15,140
2.9	8.9	40.2	59.8	3.9	5.6	83.7	1.4	5.4	15,170
3.5	7.5	39.7	60.3	2.2	5.7	84.5	1.5	6.1	15,130
Jefferson County - (East)									
3.1	9.7	37.0	63.0	1.9	5.3	84.5	1.8	6.5	15,150
3.8	7.5	36.6	63.4	1.4	5.6	84.9	1.6	6.5	15,200

III. Lower Freeport Coal

Armstrong County									
3.4	14.8	38.8	61.2	4.7	5.5	82.9	1.5	5.4	14,970
3.4	9.7	40.9	59.1	3.6	5.7	82.2	1.6	6.9	15,010
3.0	10.9	38.7	61.3	3.5	5.6	83.1	1.4	6.4	15,310
Jefferson County - (North East and Central)									
1.9	10.3	39.4	60.6	3.3	5.5	82.8	1.7	6.7	14,970
2.5	7.2	37.9	62.1	3.2	5.6	83.9	1.7	5.6	15,180
4.4	7.5	39.0	61.0	3.6	5.6	83.5	1.6	5.7	15,110
Jefferson County - (South and South East)									
3.0	10.4	35.8	64.2	3.7	5.4	84.9	1.6	4.4	15,340
2.7	5.2	35.7	64.3	1.2	5.5	86.4	1.6	5.3	15,390
2.5	5.3	37.3	62.7	1.5	5.5	85.8	1.6	5.6	15,290

Table IV (continued)

As Received		Moisture and Ash Free							
Moisture	Ash	Volatile Matter	Fixed Carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu/lb
IV. Lower Kittanning Coal									
Armstrong County									
2.7	8.5	41.3	58.7	4.6	5.5	83.1	1.5	5.3	15,100
2.3	8.7	42.1	57.9	4.6	5.6	82.5	1.5	5.8	15,060
2.4	7.9	41.4	58.6	3.6	5.6	83.7	1.5	5.6	15,180
Jefferson County									
2.9	6.9	36.9	63.1	1.3	5.6	85.4	1.6	6.1	15,220
3.0	6.9	37.1	62.9	1.0	5.6	85.9	1.5	6.0	15,320
Clarion County									
4.2	9.9	42.3	57.7	2.9	5.7	82.7	1.7	7.0	15,040
3.0	6.7	42.4	57.6	2.6	5.8	83.5	1.4	6.7	15,100
V. Upper Kittanning Coal									
Jefferson County									
3.1	9.5	36.8	63.2	3.3	5.5	84.8	1.5	4.8	15,320
Butler County									
3.7	4.4	39.0	61.0	1.0	5.5	84.1	1.7	7.7	15,080
VI. Waynesburgh Coal									
Greene, Fayette and Westmoreland Counties									
3.3	16.5	41.7	58.3	4.1	5.7	82.0	1.6	6.6	14,850
3.2	22.6	40.0	60.0	4.3	5.8	82.8	1.7	5.4	15,010
3.6	18.9	40.2	59.8	3.6	5.6	82.0	1.8	7.0	14,790
VII. Sewickley Coal									
Fayette and Greene Counties									
2.2	9.8	38.7	61.3	3.4	5.6	83.7	1.4	5.9	15,140
2.3	10.8	40.4	59.6	3.4	5.5	82.6	1.7	6.8	14,920
VIII. Redstone Coal									
Allegheny and Westmoreland Counties									
2.4	9.0	38.6	61.4	1.6	5.5	84.1	1.6	7.2	15,050
4.4	9.4	37.1	62.9	1.2	5.7	83.2	1.7	8.2	14,800
IX. Brookville Coal									
Jefferson, Butler and Mercer Counties									
2.6	10.3	40.0	60.0	4.5	5.6	83.3	1.3	5.3	15,090
3.3	12.4	44.3	55.7	3.5	5.5	81.9	1.4	7.7	14,855
5.4	6.5	42.1	57.9	2.9	5.5	81.9	1.6	8.1	14,750
X. Clarion Coal									
Clarion County									
3.6	8.2	44.6	55.4	4.1	5.7	82.6	1.4	6.2	15,050

TABLE V Average Analyses of High Volatile Coals from the Principal Seams and Counties

As Received		Moisture and Ash Free							
Moisture	Ash	Volatile Matter	Fixed Carbon	Sulphur	Hydrogen	Carbon	Nitrogen	Oxygen	Btu/lb
Allegheny County									
Pittsburgh Seam									
2-4	5-8	39.0	61.0	1.5	5.6	84.2	1.6	7.1	15,085
Upper Freeport Seam									
2-4	5-11	39.7	60.3	1.9	5.7	84.8	1.6	6.0	15,170
Redstone Seam									
2-7	9-11	38.2	61.8	1.6	5.6	83.2	1.7	7.9	14,915
Washington County									
Pittsburgh Seam									
2-3	6-9	38.4	61.6	1.6	5.5	84.6	1.7	6.6	15,105
Fayette County									
Pittsburgh Seam									
1-4	6-9	35.2	64.8	1.1	5.5	85.6	1.8	6.0	15,300
2-4	6-9	39.4	60.6	2.4	5.6	84.6	1.7	5.7	15,255
Upper Freeport Seam									
2-3	6-13	36.9	63.1	2.6	5.6	84.8	1.6	5.4	15,265
Waynesburg Seam									
3-4	13-23	39.2	60.8	3.0	5.6	83.1	1.8	6.5	14,955
Sewickley Seam									
1-3	9-12	39.3	60.7	3.9	5.6	83.4	1.5	5.6	15,145
Westmoreland County									
Pittsburgh Seam									
3-4	5-9	37.3	62.7	1.5	5.5	84.6	1.7	6.7	15,130
Upper Freeport Seam									
1-3	7-9	39.3	60.7	2.6	5.7	84.3	1.6	5.8	15,255
Redstone Seam									
2-5	9-11	38.2	61.8	1.6	5.7	83.2	1.7	7.8	14,915
Waynesburg Seam									
3-4	18-22	41.2	58.8	3.9	5.7	81.3	1.8	7.3	14,745
Greene County									
Pittsburgh Seam									
2-3	5-8	39.0	61.0	1.7	5.5	85.0	1.9	6.0	15,150
Waynesburg Seam									
3-4	16-18	41.5	58.5	3.5	5.7	82.2	1.6	7.0	14,815
Sewickley Seam									
2-4	8-11	39.5	60.5	2.6	5.5	83.1	1.8	7.0	14,970
Armstrong County									
Upper Freeport Seam									
2-4	6-9	39.7	60.3	2.7	5.6	84.2	1.5	6.0	15,145
Lower Kittanning Seam									
2-3	7-9	41.6	58.4	4.3	5.6	83.1	1.5	5.5	15,115
Jefferson County									
Lower Freeport Seam									
2-3	5-11	36.3	63.7	2.1	5.5	85.7	1.6	5.1	15,340
1-5	7-11	38.8	61.2	3.4	5.6	83.4	1.7	5.9	15,120
Lower Kittanning Seam									
2-3	6-7	37.0	63.0	1.2	5.6	85.6	1.5	6.1	15,270
Upper Freeport Seam									
3-4	7-10	36.8	63.2	1.6	5.5	84.7	1.7	6.5	15,175
Middle Kittanning Seam									
3-4	10-11	35.1	64.9	1.8	5.4	84.3	1.5	7.0	14,960
Upper Kittanning Seam									
3-4	9-10	36.8	63.2	3.3	5.5	84.8	1.5	4.8	15,320
Brookville Seam									
2-3	10-11	40.0	60.0	4.5	5.6	83.3	1.3	5.3	15,090
Clarion County									
Clarion Seam									
2-4	8-9	44.6	55.4	4.1	5.7	82.6	1.4	6.2	15,050

TABLE VI

Average Analysis for a High Volatile Coal from High-Volatile Region of Western Pennsylvania

	As Received	Moisture Free or Dry	Moisture and Ash Free
Moisture	3.0	-	-
Ash	8.0	8.25	-
Volatile Matter	34.20	35.32	38.5
Fixed Carbon	54.74	56.43	61.5
	100.00	100.00	100.0
Sulphur	1.78	1.84	2.0
Hydrogen	4.98	5.14	5.6
Carbon	75.30	77.62	84.6
Nitrogen	1.42	1.46	1.6
Oxygen	5.52	5.69	6.2
	89.00	91.75	100.0
Heat value-Btu/lb	13500	13920	15170

High-Volatile Coals

The high-volatile coals constitute more than half of the bituminous production of the state and are mined principally in Allegheny, Washington, Fayette, Westmoreland, Greene, Armstrong and Jefferson counties. They are also found in the adjacent counties, Beaver, Buttler, Lawrence, Mercer, Clarion and Elk. The map shows the counties underlain by bituminous coals and the location of the principal mining districts. The mining districts in the high-volatile region are indicated with cross-hatched areas.

These coals, typified by the Pittsburgh and the Freeport seams, are caking coals and have a wide market as steam, gas and coking coals. They are not as soft as the medium and low-volatile coals in the eastern half of the bituminous region and stand transportation well. The Freeport and Kittanning seams are softer than the Pittsburgh. The latter, in the Pittsburgh district, yields a strong blocky coal but in the other districts of the high-volatile area, the coals are fragile and easily broken into small pieces.

All of these coals burn with a long flame and require a properly designed furnace for smokeless combustion. They may be burned on underfeed stokers or in pulverized form and make good locomotive fuel. They are best suited, however, to gas and coke making, the softer and smokeless coals of central Pennsylvania being more desirable as steam fuels.

The bulk of western Pennsylvania coals has a low moisture and medium ash content. The moisture is generally about three per cent and the ash will vary between six and ten per cent. The fusion point of the ash is usually between 2300 and 2500 F.

In Table IV typical individual analyses of high-volatile coals from the principal seams in the principal counties are listed. These analyses show the general variation in the individual items of the complete analysis and may be used as a guide in selecting an average analysis for a given coal or for checking a given analysis. The moisture and ash values are on an "as received" basis and the other items are on a "moisture and ash-free" basis. From the moisture and ash-free values a complete analysis on an "as received" basis may be set up for any desired moisture and ash content.

Table V lists average analyses for the various seams in the principal counties. The moisture and ash values indicate the range in the values of these items. In general, the moisture will run about three per cent and the ash about eight per cent for these coals. In both tables, the seams and counties are arranged in approximately the order of their importance from a production standpoint. The bulk of the high-volatile production comes from the Pittsburgh and Upper Freeport seams from Allegheny, Washington, Fayette and Westmoreland counties.

In applying the average analyses in Table V to a coal in question, it is important to completely identify the source of the coal. Too much emphasis cannot be placed on the desirability of tracing the source of the coal through county and district to the seam and mine. Trade names are not reliable indications of the source of a coal except when they are the names of the mining town or district from which the coal comes. In such cases, they define a limited area but do not indicate the seam from which the coal is mined. If one seam contributes the bulk of the production from this area, however, the identification is fairly complete.

In the absence of complete identification of a coal, the general average analysis for a high-volatile coal from western Pennsylvania as given in Table VI will be helpful. This analysis may be used for most purposes without serious error. It is made up to approximate the composition of the bulk of the high-volatile coal produced in the principal counties. However, no such average is as reliable as a complete analysis of a representative sample by a competent chemist but in the absence of such data its use is justified.

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STEAM ENGINEERING ABROAD

As reported in the foreign technical press

District Heating in Copenhagen

The Steam Engineer (London) for March describes the district heating system supplying certain areas in the City of Copenhagen. Like most district heating systems this one represents a process of evolution dating back to 1920 when the boiler plants of a number of municipal institutions were connected with that of the city's Dersted Power Station to care for peak load and standby service. Later, during the period from 1924 to 1928, three heating plants were established in different load centers to supply steam at 150 to 175-lb pressure and hot water at around 200 F.

In the mean time, however, the demand of the district served by the Gothergrade station, the largest of these heating plants, grew to approximately 150,000 lb of steam per hour. As a consequence a high-pressure boiler plant was installed to operate at 560 lb per sq in. and 700 F. This supplies steam to a 2000-kw back-pressure turbine exhausting at 150 lb either to the distribution mains or to two existing 5000-kw condensing turbines in the station. A Ruths steam accumulator is installed for storing excess steam and balancing varying demands for heat and power. About 15 per cent of the heat is distributed to customers in the form of hot water.

Welded seamless steel piping is used throughout the distribution system with expansion bends located at certain distances in concrete expansion chambers. The pipe, which is supported on roller bearings, is wrapped with a few layers of paper around which is placed cell-concrete to provide the necessary insulation. After the main has been in service a short time the paper carbonizes and allows the pipe to move freely within the cell-concrete lagging. To prevent the roller bearings from being obstructed by the cell-concrete, they are covered with paraffin which melts when the pipe becomes hot.

Operating Results at Battersea

Engineering of March 20 reports operating and test performance at the Battersea Station of the London Power Company. This outstanding British power station contains six stoker-fired boilers each of 320,000 lb per hr rated capacity, equipped with both economizers and air heaters, and supplying steam at 615 lb and 875–900 F to two 80,000-kw turbine-generators. A third machine of 105,000-kw capacity has just been added and three more boilers of 375,000 lb per hr output are being installed.

During 1934 a total of 354,966,280 kwhr was generated at an average fuel consumption of 1.06 lb per kwhr with a corresponding station thermal efficiency of 27.24 per cent at an average yearly load factor of 53.7 per cent. With a further increase in load and improvement in load factor during 1935 the performance was still better, reaching a maximum station efficiency of 29 per cent during November and December when the corresponding load factor was around 85 per cent. Boiler efficiency during this period was maintained at approximately 88 per cent.

Two 24-hour boiler tests are reported, one with Scotch washed pea coal of 11,610 Btu per lb, 12.51 per cent moisture and 7.4 per cent ash; the second with Welsh coal of 14,040 Btu per lb, 5.71 per cent moisture and 5.16 per cent ash. The respective net efficiencies were 86.98 and 88.46 per cent.

Steam consumption tests on one of the 80,000-kva turbine-generators is also reported. These showed a low point of 9.16 lb per kwhr at 52,800 kw corresponding to the service load which was slightly better than the guarantee. At the maximum continuous rating of 67,200 kw the steam consumption was 9.35 lb per kwhr.

Determining Ash Content of Coal

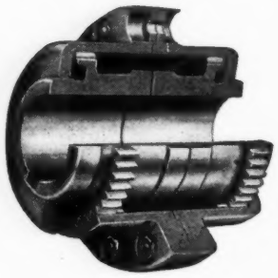
Wärmewirtschaft of January 1936 comments on some investigations dealing with the influence of the ash content of coals, as conducted at the laboratory of the Zschornewitz power station. It is pointed out that the usual method of determining the ash content by weighing the residue remaining after the combustible matter has been burned out is frequently inaccurate inasmuch as this may be quite different from the original weight of the mineral substances in the coal. This is because certain minerals lose weight in the furnace due to volatilization of the combined water and oxygen and represent endothermic reactions whereas others, such as ferrous oxide, actually gain weight in the furnace and with pyrites the reactions are exothermic. The reduction of weight was found to depend upon the character of the minerals in the coal and the temperature in the furnace. With one coal tested this was found to be as much as 30 per cent over a furnace temperature difference of 750 F.

The fact that part of certain minerals in the coal go into gaseous form in the furnace and the splitting off of volatile substances was found to materially affect the combustion calculations.

Recirculating Flue Gases

The Lutz Process of recirculating flue gases was proposed in Germany some years ago and has met with only limited application, there being only about twenty stations in that country in which it is being employed. Its advantages under certain conditions as well as its disadvantages are reviewed at length in the February issue of *The Fuel Economist* (London). For instance, it is pointed out that with a boiler operating at light load there may not be sufficient cooling air to protect the grates unless considerable excess air is provided whereas

Specifying



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the introduction of flue gases will protect the grate against burning. Also the lowering of the temperature of the fuel bed will prevent fluidity of the slag and lessen clinker formation. Operating results from several plants are cited to show lessened grate maintenance and with some coals increased efficiency due to a more uniform fuel bed.

80,000 Tons of Coal-Oil

The new Billingham-on-Tees plant of Imperial Chemical Industries for the production of oil from coal had, up to the end of February, produced 80,000 tons (7,500,000 gal) of oil. The plant is reported to be now working at full capacity.—*Industrial Britain*, March 1936.

Further Discussion on James Watt

I was interested in Mr. Taube's article in the January issue on James Watt, and his analysis of boilers used in those days is useful. It is surprising that Boulton & Watt did not contribute to boiler improvement; possibly this was because Watt was really an instrument maker. He was dependent on Wilkinson, the ironfounder, for making and boring the large cylinders then much the most important part of pumping engines. Wilkinson was not the first to use a cylinder boring machine for John Smeaton, civil engineer of Leeds designed one for boring the cylinders of Newcomen engines. The first boring machine having a screw feed, was made by Matthew Murray and this type was copied by Murdock after he had visited Murray's works.

Murray began to make engines about 1797 and he was the first to get away from the reciprocating beams. He made engines with the accurate straight-line motion to change reciprocating into rotary motion and his method was superior to Watt's parallelogram and to Murdock's "sun-and-planet" motion.

Murray was also the first to use the three-ported slide valve with lap and lead and he made a number of other improvements. There were also other engineers, such as Trevithick, Bull, Hornblower and, if Boulton & Watt had not had the 25 years' monopoly, engine building would have advanced much more rapidly than it did.

Emmett of Birkinshaw near Bradford had a cylinder boring mill and he built the Newcomen engine that was erected at Rothwell near Leeds and which worked for well over a century. In 1769, when Watt applied for his patent, Smeaton stated that about 150 Newcomen engines had then been made.

The late Professor Unwin had in his possession a statement that Watt made an engine in 1785 for Whitbreads at Birmingham, bearing the inscription:

"The expense in fuel reduced one-half by Mr. John Smeaton, F.R.S., of Austhrope, in the County of York, civil engineer, 1768."

The engine referred to was evidently the one that Smeaton partly constructed in his workshop at Leeds in 1768 for the New River Company of London and which pumped water from a reservoir.

Watt was clever, but he certainly had failings and an almost feminine jealousy, for he held up progress by insisting on low pressures, and nearly got an Act of Parliament passed to limit it to 10 lb. He stopped Murdock, who was much more of an engineer, from proceeding with steam locomotion and he expressed himself as against steamboat development.

As stated in Mr. Taube's article, he tried to dissuade Boulton from getting orders for *rotative* engines and when such engines were made, they had the Murdock "sun and planet" motion, not Watt's. The firm of Boulton & Watt prosecuted the Hornblowers and had the younger one kept in prison for debt, yet it was he who first conceived the important principle of compounding.

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